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Linguistics, Archaeology
and
the Human Past

# INTER-REGIONAL INTERACTION AND URBANISM IN THE ANCIENT INDUS VALLEY

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Randall William Law



Indus Project
Research Institute for Humanity and Nature
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# FOREWORD

Toshiki Osada
Project leader of the Indus Project
Professor, Research Institute for Humaniaty and Nature

It is a pleasure for me to publish Dr. Randall Law's magnum opus "Inter-regional interaction and urbanism in the ancient Indus Valley: a geologic provenience study of Harappa's rock and mineral assemblage" as a special publication of our Occasional Paper.

I have conducted the Indus project at the Research Institute for Humanity and Nature, Kyoto since 2006. The full title of our RIHN project is "Environmental Change and the Indus Civilization". This research project examines the social character and environmental context of the Indus civilization, and attempts to determine how they are related to the civilization's short life and rapid decline. In particular, we aim to evaluate the impact of environmental change on the subsistence economy and trade network that sustained the Indus civilization's urban system. We have carried an archaeological excavation at Kanmer, Gujarat and Farmana, Haryana both in India. Final reports for both excavations will be published by the end of March, 2011. The project unites a range of internationally recognized and interdisciplinary scholars. We have so far published ten volumes of Occasional Papers in which the full variety of scholars collaborating in the project presents papers as the project's latest results.

This book is an updated version of Randall Law's Ph.D. dissertation, which was submitted to the University of Wisconsin-Madison in 2008. He conducted the bulk of this research under the guidance of Professor Jonathan Mark Kenoyer, who is one of the most famous and active archaeologists in this field and co-director of Harappa Archaeological Research Project. Dr. Law's intensive field work took him across an area that ranged from the Northern Areas of Pakistan to Gujarat, India in the south and from Makran coast of Balochistan in the west to the Aravalli Range Rajasthan in the east. He has recently expanded his research activities to the eastern Arabian Peninsula. Along the way he collected geologic samples of rocks and minerals used by Harappans such as steatite, chert, limestone, agate and copper. These samples were later directly compared to artifacts from Harappa using a range of methods such as X-ray diffraction analysis, electron microprobe analysis, Pb isotope analysis and neutron activation analysis. I believe Dr. Law's research goals dovetail nicely with those of our RIHN project and, thus, I have decided to publish his work as part of our Occasional Paper series.

I hope Dr. Law will continue his original work and lead his generation in Harappan Studies.

# PREFACE

Jonathan Mark Kenoyer
Professor, Department of Anthropology
University of Wisconsin-Madison

Writing a book about rocks and minerals of a long dead civilization is a daunting task, and while there are many who have taken up the challenge few have succeeded like Randall Law. Without doubt Randall's doctoral dissertation, which is now being published in this well illustrated book, represents the most important recent contribution to the ongoing studies of the Indus Civilization. It is an outstanding example of how to develop new strategies to study old problems, and how to squeeze blood from old rocks and make a dead civilization live again. The old problems that have been examined in this book relate to the origin and development of the Indus Civilization (2600-1900 BC), an urban society that emerged in the vast plains of the ancient Indus and Ghaggar-Hakra-Saraswati Rivers. The "blood" or information that Randall has extracted from the study of rocks and minerals has been used to test long held models on the development of inter and intra-regional exchange and its role in the emergence of Indus urban centers. The results of his studies have brought to life a whole new set of interaction networks that connected Indus cities such as Harappa, to other Indus settlements and regional resource areas.

I met Randall Law at a lecture I gave as part of a panel at the Anthropological Association of America Annual meetings in San Francisco in November 1996. The lecture was titled "Urban Development and Craft Production at Harappa, 3300-1700 B. C." and included discussion of pottery making, lithics and stone bead production at Harappa. After the lecture we had a chance to talk about his interests in studying the archaeology and trade networks of Western China and Central Asia. Although he was not focused on the Indus I pointed out to him that there were possible connections between the Indus and Western China and that he might want to expand his research in this area. When he came to Madison to start graduate studies with me, he had recently spent several months in China and was hoping to carry out his dissertation research somewhere in Xingjiang. However, over the course of his graduate studies, and after working with me in the study of rocks and minerals from the site of Harappa, he decided to shift his focus to the Indus. This shift would still allow him to explore the regions to the north of Harappa, including northern Afghanistan and parts of Central Asia. Based on the success that he has had in these studies, I am confident that he will eventually extend his explorations to the area of his original interest, Western China, in the coming years.

I was thrilled with Randall's decision to work at Harappa, and although I had already begun collecting comparative samples of rocks and minerals from many parts of Pakistan and India, I knew that I would not have time to exhaustively collect samples from all of the potential source areas. Because of his strong science background

and his passion for geology and geography I knew that he would go far beyond anything that I had ever done. Over the course of his dissertation studies it became quite clear that he had a special gift for searching out rock sources and collecting samples from obscure regions. He also had the ability to write successful applications for funding to undertake both field research and laboratory analysis. His ability to understand complex archaeometric issues in the analysis of raw materials ensured that he used the best possible methods for sourcing various types of rocks. Furthermore, his engaging discussions and the fact that he was willing to spend generous amounts of his time helping others, opened up the doors and comparative collections of major institutions and local scholars, as well as guidance of enthusiastic villagers in all regions of Pakistan and India. I was fortunate to be able to share in the excitement as he began to collect samples and visit different source areas. In the summer of 2000 we took a road trip from Harappa to Skardu to collect rock samples for his dissertation and he loaded so many rock samples into the Harappa Toyota Corolla that it broke the rear springs. It was important to collect all of these rocks, and because of his extraordinary efforts, he has been able to obtain an unparalleled set of original samples of rocks and minerals from almost every possible source area surrounding the Indus and Ghaggar-Hakra-Saraswati River plains.

Randall's multi-disciplinary approach to the investigation of early urbanism combines geology and scientific materials analysis, with state of the art archaeological excavations of a complex urban center. The primary archaeological data set is from the renewed excavations at the site of Harappa, Pakistan, begun by Dr. George F. Dales and me in 1986 (Dales 1989), and continuing up to the present as the Harappa Archaeological Research Project (Meadow 1991, Meadow and Kenoyer 2008). The overall goal of the project has been to understand the origin and development of Harappa as one of the major urban centers of the Indus Civilization (Dales and Kenoyer 1991). Many different strategies were developed to examine all aspects of the site. One important approach was to collect samples of raw materials, specifically rocks and minerals, from all excavation areas so that in the future, a dedicated scholar, in this case Randall Law, would be able to carefully study each and every fragment to reconstruct the trade and exchange networks that brought these materials to the site.

This book begins with a well-articulated introduction that outlines the overall objectives and the theoretical frameworks being used, as well as the various methodologies needed to address specific questions. He has done an excellent job in developing an engaging writing style that tells the story of a rock, its discovery and analysis, and its overall importance to his research questions, while at the same time presenting details that will be of interest to specialists. Over the course of his dissertation research, he employed multiple complementary analytical techniques to carry out analyses of more than 3000 archaeological and modern geological samples. With the results from these studies he was able to compile for the first time, a detailed provenience map for the archaeological rock and mineral samples from Harappa and several other contemporaneous sites. He has also been able to convincingly demonstrate that only a limited number of source areas can be linked to specific raw materials from Harappa. This critical use of scientific data has allowed him to generate maps of potential source areas that would have supplied Harappa with specific raw materials during different occupational phases, (circa 3500-1700 BC). He has intentionally kept his conclusions conservative, because there are always more sources that need to be sampled, and the widespread extent or internal variation in some geological deposits are often too large to

allow pin-point accuracy for sourcing. Nevertheless, the conclusions that he does reach are extremely important and serve to address two of his primary lines of inquiry regarding changing inter-regional interaction/acquisition patterns, and variations in the acquisition and use of raw materials at Harappa itself. One of the most important discoveries has been the fact that many of the important raw materials used for creating both utilitarian and prestige goods came to Harappa from sources located far to the north in the mountainous regions of the northern Indus valley. At most of these source areas there is no evidence for the presence of Harappans or in some cases there are no reported prehistoric sites at all. This has made it difficult to answer one of his other research question regarding the identification of specific communities that were providing raw materials to the Harappan cities. Clearly more research needs to be done on this topic but due to the current security situation in these regions, such studies will need to be undertaken in the future.

It is highly unlikely that any one person in the near future, will be able to collect the vast range of materials that he has accumulated and undertake a comparative study of this scale. I want to thank Randall for this stimulating presentation of a complex set of data that will take many more years to fully appreciate. Every time I prepare a lecture or write a new article, I am able to include new updates and insights based on his innovative research. This book and its extensive appendices will be a major reference for any future studies of the Indus region and beyond, not only for rocks and minerals, but all aspects of regional and extra-regional interaction.

In conclusion I also want to commend the publishers and editors of this series, Dr. Toshiki Osada and Dr. Akinori Uesugi, for selecting this outstanding piece of research for their publication series. I am honored to have been able to contribute to various aspects of this project and look forward to many more years of productive collaboration.

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This book is an updated version of my PhD dissertation, which I defended at the Department of Anthropology, University of Wisconsin-Madison in May of 2008. I am deeply grateful to Prof. Toshiki Osada and to the Research Institute for Humanity and Nature (RIHN), Kyoto for agreeing to publish it and for sponsoring my August 2010 stay at the institute in order to complete the revisions. I am likewise grateful to Dr. Akinori Uesugi at the RIHN, for giving up his valuable time in order to format the final text and illustrations. Thanks also to Dr. Steve Weber, Dr. Marco Madella, Endo Hitoshi and Takeru Sonoda for their friendship, advice and assistance during my stay in Kyoto. I wish to express my heartfelt gratitude to Prof. Asko Parpola. It was his encouragement at the January 2010 RIHN-sponsored roundtable in Bhuj, India, that prompted me to pursue publishing my dissertation in this form.

Special thanks are due to the members of my dissertation committee – Drs. J. Mark Kenoyer, T. Douglas Price, Jason Yaeger, Sissel Schroeder, Nick Cahill and James H. Burton – for agreeing to read my beast of a thesis over a short span of time, several years after I first promised to deliver it. I am particularly grateful to Dr. Price who, as the Director of the Laboratory for Archaeological Chemistry (LARCH) at the University of Wisconsin-Madison, generously provided access to the instrumentation on which a great deal of the data presented here were produced. And I wish to both thank and blame Dr. Burton, the associate-director of the LARCH. It seemed that every time I walked into Jim's office or the lab I came away inspired and brimming with ideas for new studies that I had to undertake (was absolutely convinced were imperative) for this research project. It literally added years to the production my dissertation. It was completely worth it.

I am grateful to all the members of the Harappa Archaeological Research Project (HARP) but most especially to the project directors Drs. Richard Meadow and J. Mark Kenoyer for inviting me to come to the site, teaching me to excavate there and allowing me to study the materials that they and others had labored many seasons to recover. Many thanks also to Drs. Rita Wright, Steve Weber, William Belcher, Heather Miller, Sharri Clark, Brad Chase, Mark Smith, Rae Beaubian, Mr. Nadeem Ghouri (and his wonderful family in Lahore) and all of the camp staff, site workmen and various friends of the HARP.

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All errors or oversights contained herein are mine and mine alone.

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On October 15th 2005, Prof. Hamidullah died in a helicopter crash while taking part in relief efforts for the victims of the October 8th 2005 earthquake in northern Pakistan.

This book is dedicated to him.



Prof. Dr. Syed Hamidullah, near Jamrud, NWFP, December 2000

# CHAPTER 1

# OBJECTIVE, OVERVIEW AND THEORY, HARAPPA AND LINES OF INQUIRY

## CHAPTER INTRODUCTION: THE PRINCIPAL RESEARCH OBJECTIVE

This study is an examination of inter-regional interaction and urbanism in the Greater Indus region[1] of Pakistan and northwestern India from the mid-fourth through the early second millennium BC - a period that encompassed the development, existence and decline of South Asia's first urbanized society, the Indus Civilization (ca. 2600 to 1900 BC). The principal research objective is to identify the sources (geologic provenience) of rock and mineral (stone and metal) artifacts excavated at Harappa, which is a site that grew from a small village to become one of the largest Indus Civilization cities. Provenience determinations are used to address *three lines of inquiry* into the inter-regional and intra-site socio-economic relationships of those who dwelled at Harappa during different periods in its history:

1) *Who in the Greater Indus region or beyond were the residents of Harappa interacting with when they acquired rock and mineral resources?*
2) *How did inter-regional interaction/acquisition patterns change over time?*
3) *Did synchronic variations in rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?*

Underlying this study is the simple premise that rocks and minerals, from the prestige materials used to create items that signified wealth and social status to the utilitarian materials necessary to carry out day-to-day tasks, were integral to the development and functioning of early urbanized societies. The need to acquire these vital resources would have been a major impetus for interaction between the first city-dwellers of the Indus Valley, which is a region where stone and metal sources are scarce or absent, and peoples of the neighboring highlands where they occur. Moreover, power garnered from the control of such resources would have been a significant factor in promoting and maintaining the social and political stratification characteristic of an urbanized society like the Indus Civilization. Elucidating rock and mineral acquisition networks through provenience studies of stone and metal artifacts is also an excellent method with which to examine the broad-scale communication and exchange phenomena that Joseph Caldwell conceptualized (1964) as *interaction spheres* (also called *interaction systems* – Shaffer 1992: 442). Archaeologists have come to regard this form of inter-societal contact as an important stimulus for socio-cultural change and innovation (Schortman 1989: 52; Trigger 1989: 330-337). The current state of research indicates that urban lifeways in northwestern South Asia emerged in a milieu of regionally distinct cultures that maintained contact with one another through extensive trade networks and seasonal migration regimes (Kenoyer 1991a; Mughal 1990; Possehl 1990; Shaffer 1992). The resultant urbanized society was characterized by a complex series of internal interaction systems (Kenoyer 1995b), some of which articulated externally with other complex interaction spheres outside of the Greater Indus region (Edens 1993; Hiebert 1995; Lamberg-Karlovsky and Tosi 1973; R.P. Wright 1984). It has been proposed (Possehl

1) see definition on p. 31

2002, 2007) that the Indus Civilization was part of an even larger, trans-regional system – the "Middle Asian Interaction Sphere," which connected societies from Mesopotamia to the Indus Valley during the third millennium BC. These varying spheres of interaction and the emergence of urbanism in the Greater Indus region are examined here through a series of both broad and fine-scale geologic provenience studies of Harappa's rock and mineral artifact assemblage.

In order to address three lines of inquiry outlined above, the entire assemblage of stone and metal artifacts recovered by the Harappa Archaeological Research Project since 1986 was categorized, periodized and quantified. Nearly 3000 of those artifacts representing eight different rock or mineral varieties were directly compared to geologic samples collected from potential source formations located across the Greater Indus region. Comparative methods ranged from examinations of basic macroscopic and mineralogical attributes to highly precise and accurate isotopic and elemental assays. In the end, provenience determinations for over 2100 stone or metal artifacts were generated.

The large body of new data produced for this study has permitted the testing of numerous hitherto untested assumptions regarding where it was that Indus Civilization peoples, their Early Harappan predecessors and their Late Harappan successors, acquired rock and mineral resources, who they were interacting with as a consequence and how such resources were distributed in an urban setting. Many findings corroborate widely held views of resource acquisition and inter-regional interaction during the late-prehistoric period in northwestern South Asia. Other findings, however, require that certain assumptions be revised. For instance, multiple lines of evidence now point to the existence of early and enduring acquisition networks between Harappa and source areas to the north of the Indus Valley, which suggest that relations with the peoples of that region were more significant than was generally supposed.

Synchronic spatial examinations of Harappa's assemblage were also revealing. It appears that, by and large, residents of all parts of the settlement had access to the same varieties of raw materials from the same sources. However, a few variations are evident that suggest groups in some areas of the site may have, at times, favored materials from certain sources and/or controlled specific kinds of stone. Finally, it has been determined that, during every period at Harappa, some rocks and minerals were derived from sources outside of the Greater Indus region, thus indicating that external trade was an important and continuous aspect of the socio-economic lives of the site's residents. Most of those external sources were located in neighboring highland areas, however. Evidence for external trade with distant regions such as Arabia and Mesopotamia remains, at least in terms of the stone and metal artifact assemblage at Harappa, elusive.

Although the primary focus of this book is Harappa's rock and mineral assemblage and the urban phenomenon at that site, the data generated are pertinent to the broader issue of inter-regional interaction and its relationship to the initial manifestation of urbanized society in South Asia. In order to bolster a broad-scale perspective, this study has been supplemented with geologic provenience analyses of select stone and metal artifacts from over a dozen additional prehistoric sites in Pakistan, India, Afghanistan and Iran. These data, although limited, have revealed (or confirmed) the existence of several broad-scale inter-regional resource acquisition networks as well as more localized regional ones.

In this chapter, I first provide an overview of the Indus Civilization. The theoretical orientation from which the issues examined in this book are approached is then laid out in discussions of urbanism and its preconditions, inter-regional interaction, long-distance trade and the control of essential resources, the importance of rock and mineral resources to urbanized societies and the utility of geologic provenience studies in research of this kind.

The physical and cultural/chronological aspects of Harappa are then presented. Lastly, the three lines of inquiry are reviewed and an outline is provided.

## INDUS CIVILIZATION OVERVIEW AND THEORETICAL ORIENTATION

### The Indus Civilization

In the 1920s and 30s, excavators at the sites of Harappa (Vats 1940) and Mohenjo-daro (Marshall 1931b) exposed the remains of a civilization in northwestern South Asia that was roughly contemporaneous with those of Sumerian/Akkadian Mesopotamia and Old Kingdom Egypt (Figure 1.1). This previously unknown society possessed the most well-planned and maintained cities of its era, a system of writing and standardized weights and measures, technologically advanced craft industries and other aspects of a distinctive material culture that, because they were so remarkably similar across a broad geographic expanse, indicated the existence of a widely shared ideology maintained through extensive trade and communication networks. Although its cultural roots were initially believed to lie in western Asia (it was first designated the "Indo-Sumerian" Civilization – Marshall 1924: 528), it was soon recognized (Marshall 1928) that this society, which has since come to be known variously as the Indus, Indus Valley, Harappan or Sarasvati-Sindhu Civilization (I hereafter use *Indus Civilization*), was fundamentally indigenous in origin.

The Indus Civilization was also, for a great many reasons, an enigma to scholars. Although it was undeniably a complex and highly integrated urbanized society, it lacked (or appeared to lack) certain features exhibited by other early civilizations that were indicative of pronounced social stratification and institutionalized authority. There were no clearly recognizable palaces, opulent tombs or temples that could be associated with either a secular or religious elite ruling class. Nor were there any explicit expressions/depictions of political power such as monuments or murals. Evidence for organized warfare or any other form of violent coercive behavior was practically non-existent. In short, there were few *overt* archaeological indications as to either who governed this society or how they amassed the power and authority to do so. Written records, which had provided valuable insights into these aspects of early Egyptian and Mesopotamian civilizations, were of no help as the Indus script could be not read. Researchers were, therefore, faced with a purely archaeological record of a complex society that was, in several significant ways, at odds with the suite of traits (first outlined by V. Gordon Childe in 1950)

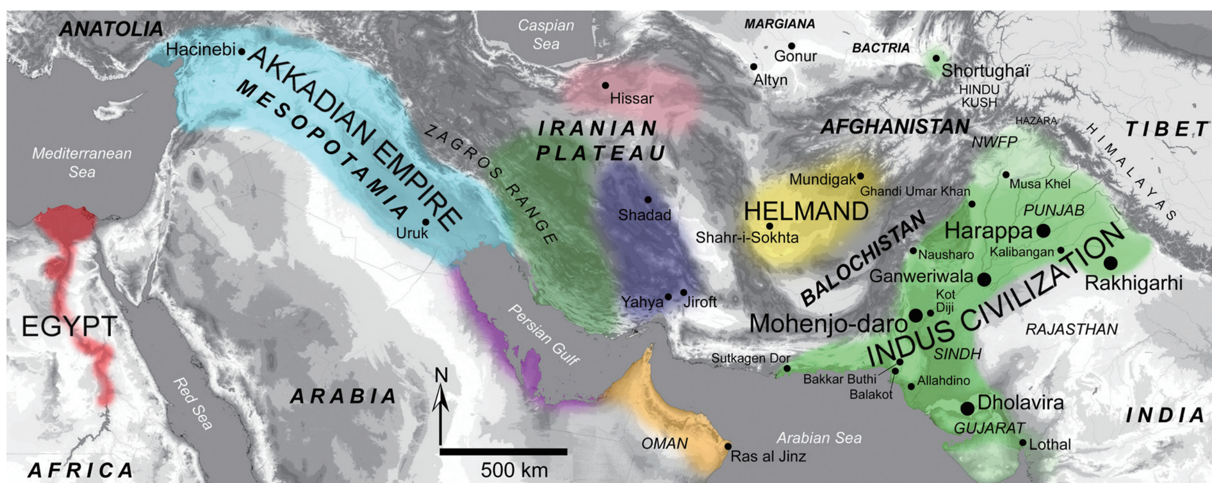



**Figure 1.1** Select Old World Civilizations (ca. 2350 BC) and sites mentioned in Chapter 1.

then generally regarded as typical of early urbanized civilizations.

Interpretations of that record by Sir John Marshall (1931b), Ernest Mackay (1948), Sir Mortimer Wheeler (1950), Stuart Piggott (1950) and others were remarkably astute and, in a great many respects, are still benchmarks for understanding the Indus Civilization. However, they are also products of a nascent era – both in terms of archaeological inquiry in general and South Asian archaeology in particular. In trying to reconcile the somewhat atypical (and then quite limited) record of the Indus Civilization with those of other ancient urbanized societies, early scholars came to some disputable conclusions. For example, their characterizations of Indus society as exhibiting "complete uniformity" (Marshall 1931a: 91), "monotonous regularity" (Piggott 1950: 136) and "astonishing sameness" (Wheeler 1950: 29) across the area in which it is found are, for the most part, significantly overstated (Possehl 1992b). High areas at sites were often regarded as defensive "citadels" and certain large structures as state-run "granaries" when, in fact, there is little evidence that such features served those purposes (Fentress 1984; Meadow and Kenoyer 2008; Possehl 2002b: 103-104). A few rare incidences of human statuary at Mohenjo-daro were thought by some to be depictions of austere "priest-kings" who wielded "autocratic and absolute power" (Piggott 1950: 153). In actuality, it is not possible to say who such statuary depicted or if (and much less how) they ruled Indus society (Possehl 2002b: 115).

Our knowledge of the Indus Civilization grew tremendously during the latter half of the 20th century. Surveys brought to light well over 1000 Indus settlements and more than 100 of those sites were excavated (Possehl 2002b: 63). Moreover, investigations and comparative studies of ancient civilizations around the world have significantly broadened our understanding of how early complex societies developed and of the social, economic and political variations that they exhibited (Trigger 2003). Yet early in the 21st century the Indus Civilization remains as enigmatic as it ever was. Its script has resisted all attempts at decipherment (Parpola 1994) and many fundamental questions about its origins, existence and decline remain to be answered. Chief among these questions concern the development and nature of the extensive networks of inter-regional interaction that permitted an urbanized society to emerge and then be maintained for roughly a 700 year period across the culturally and geographically diverse landscape of northwestern South Asia (Allchin and Allchin 1997; Chakrabarti 1984; Fairservis 1975; Gupta 1999; Kenoyer 1998; Mughal 1990a; Possehl 1999; Shaffer and Lichtenstein 1989). It is this issue that is at the heart of this study and which I am examining through geologic provenience studies of rock and mineral artifacts from Harappa and other prehistoric sites.

### Urbanism and its preconditions

The Indus Civilization represented the initial manifestation of urbanized society in South Asia and Harappa was among the very first urban centers to emerge in that region. Throughout this book, I endeavor to be attentive to the subtle but important differences in the meanings of the terms "urban," "urbanism" and "urbanization" (Smith 2003: 12-13 after Fox 1977; see also Cowgill 2004: 527). *Urban* refers specifically to characteristics of cities and their populations while *urbanism* is used in reference to the "general phenomenon of cities" (Smith 2003: 13). *Urbanization* refers to the emergence of cities within a "territorial expanse" and the process by which peoples of that area, whether they dwell in a city or not, become linked in a "center dominated ethos" (ibid.).

Despite the efforts of scholars in a wide range of fields, "no universal or comprehensive definition of the city" has ever been formulated that can encompass the "specificity and uniqueness" exhibited by all of its historical variants, most especially those in ancient South Asia (Eltsov 2005: 319). Nevertheless, Harappa

**Figure 1.2** General preconditions for urbanism and the rise of state-level society (from Kenoyer 1991a: 343-349). *Emphasis added*.

1) Diversity of subsistence base and *resource variability* which have the potential for the production of surplus.

2) Development of social and economic *interaction networks* between major ecosystems and resource areas.

3) *Technological capability* to fill specific needs of urban and state-level society.

4) Differentiation in status on the basis of access to *essential resources* and the ability to control distribution of essential resources.

and other comparable Indus Civilization settlements like Mohenjo-daro, Dholavira, Ganweriwala and Rakhigarhi would undoubtedly be considered cities in all but the most rigid of classification schemes. Their populations are estimated to have been in the tens of thousands – orders of magnitude greater than the typical Indus Civilization settlement; there is evidence at most of them for massive perimeter walls and multiple, well-demarcated neighborhoods; they were regional centers where a huge range of specialized crafts were produced using raw materials often brought from sources hundreds of kilometers away; and although no definitive examples of administrative and/or religious institutions (palaces or temples) have been identified[2)], there are monumental buildings at several of them that obviously served some very important communal or private functions (Bisht 2000; Chakrabarti 1995; Jansen 1994; Kenoyer 1997a; Mughal 1994a; Nath 1998; Possehl 1990).

Although its most prominent characteristic is the city, urbanism is actually an extra-regional phenomenon consisting of interrelated environmental, demographic, technological and social components (Wheatley 1972). Based on those components, Kenoyer (1991a) defined four *general preconditions for urbanism and the rise of state-level society* in ancient South Asia. I have listed these in Figure 1.2 and emphasized (using italics) several key aspects that I focus on throughout this book.

Kenoyer's (1991a) first precondition highlights the necessity of a diverse subsistence base and *resource variability*. The roughly 40 distinct kinds of rocks and minerals found in Harappa's artifact assemblage (Chapter 4) are a testament to the rich and highly varied geologic resources that were available across northwestern South Asia (discussed in Chapter 2). The development of social and economic *interaction networks* between the different ecological zones and resource areas of that region (Precondition 2) provided, in essence, the glue that bound together (integrated) the widely dispersed peoples of the Indus Civilization and the avenues through which subsistence goods and other essential resources could be distributed to them. Identifying these networks through geologic provenience studies of rock and mineral artifacts from Harappa is the central focus of the research presented here. Among the many *technological capabilities* that had to be developed to fill the specific needs of an urbanized society (Precondition 3) were bullock carts and large river boats (Kenoyer 2004; Miller 2006). Such transportation technologies were required to move goods in bulk sizes and quantities over long distances (Law 2006). Their development and use is examined indirectly through the study of bulk goods like grindingstone (Chapter 5) and limestone (Chapter 11)

2) This might be changing. Based on his recent reinterpretation of architectural patterns at Mohenjo-Daro, Massimo Vidale argues (Vidale 2010) that a heterarchy of elites groups dwelled at the site in multiple "citadel-like walled enclosures" that can only be described as palatial.

– the latter of which was, at times, transported over 800 km to Harappa in individual pieces weighing in excess of 100 kg. Differentiation in social status based on *access to essential resources* and the ability to control their distribution is Kenoyer's fourth and final precondition. I argue shortly that rocks and minerals were as essential to the development and maintenance of early urbanized societies as were surplus grain or livestock. The issue of differential access within Indus society to such resources is examined by comparing (in Chapter 4) the rock and mineral sub-assemblages from the various discrete habitation areas at Harappa (discussed below), as well as by attempting to detect intra-site variations in the geologic source proveniences of select material varieties that were used in all parts of the settlement.

All four of the above preconditions were fulfilled in the millennia leading up to coalescence of the Indus Civilization at around 2600 BC. The appearance of cities across northwestern South Asia at that time is indicative of the emergence of a society that was markedly more expansive and complex than the various regional, village-based ones that had existed there before. There is debate as to whether this initial urbanization was an abrupt process (perhaps occurring in a single century – Shaffer and Lichtenstein 1989: 123) or a long and gradual one (Kenoyer 1997a). There is also disagreement as to whether or not the Indus Civilization was a state-level society (see Possehl 1998b and Kenoyer 1994b for opposing views on this issue). Based on evidence that is reviewed in Chapter 2, I take the position that the Indus Civilization was the product of an extended phase of steady developments (occurring circa fourth and early third millennium BC and designated the "Early Harappan" Period by Mughal 1970, 1990a) and that it was probably organized politically as state (or at least an amalgam of city-states). However, the latter issue need not be definitively resolved for this present study of urbanism to move forward. A current trend in research of this kind involves "decoupling our understanding of cities from our assessment of early states" (Smith 2006: 98). The settlement of Harappa grew from one of many small villages located on the alluvial plains of northwestern South Asia to become one of a few major urban centers in that region. What I seek to shed light on through the study of its rock and mineral artifacts are the local, regional and extra-regional *actors* – the different groups of people residing at the site itself and those peoples (both Harappan and non-Harappan) dwelling in regions often great distances from it, who were involved in the urbanization process and, specifically, their connections (interaction) with one another.

## Inter-regional interaction, long-distance trade and the control of essential resources

The vast geographic area across which Indus Civilization settlements are found and the highly similar material culture attributes that those sites exhibit together point to the existence of well-developed and far-reaching inter-regional interaction networks binding the civilization's "various social groups as a distinct cultural entity" (Shaffer 1988: 1316). It is through such networks that peoples from distant regions come into contact with one another, material resources are transferred from places where they are abundant (or present) to places where they are scarce (or absent), and "ideas are exchanged, inventions are transmitted, and so are ambitions and aspirations" (Renfrew and Bahn 1996: 336). Their establishment and/or intensification is widely believed to have been an important stimulus toward the development of new and increasingly elaborate forms of social and political organization in many parts of the ancient world (Algaze 1989; Chang 1986; Childe 1950; Dematte 1999; Earle 1991; Feinman and Nicholas 1992; Kenoyer 1995b; Lamberg-Karlovsky 1972; Rathje 1971; Renfrew 1986; Schortman and Urban 1992b; Stein 2002). My objectives are to identify the inter-regional interaction networks of

the Indus Civilization (at least some of them); to determine if and how they were transformed during the emergence and existence of that society; and to examine the possibility that certain groups of people living at Harappa controlled or had greater access to particular networks.

Inter-regional interaction may occur in various forms, such as "trade, warfare, migration, or the diffusion of ideologies" (Stein 1999: 3). All of these no doubt took place during the period that the Indus Civilization emerged and existed. Some forms, however, appear to have been more significant than others in terms of their role in the development and maintenance of that urbanized society. For example, while there were almost assuredly violent confrontations (warfare) between late prehistoric peoples dwelling in different parts of northwestern South Asia, there is no evidence that a level of conflict existed similar to that which accompanied the formation of Uruk city-states in Mesopotamia (Gat 2002) or the unification of Early Dynastic Egypt (Wilkinson 1999). Nor are there any iconographic depictions of captives or conquests that would suggest the integration of Indus society was preserved through any form of "military coercion" (Kenoyer 1991a: 347). The peaceful movement (migration) of pastoralists and various "itinerant" peoples (Possehl 1999: 14-16) was likely a more influential form of interaction. Starting in the early Neolithic (ca. 6000 BC), pastoralists established patterns, which continue to this day, of seasonal, long-distance migration between the plains of the Indus Valley and the highlands surrounding it (Bozdar *et al*. 1989; Fairservis 1975: 210; Meadow 1996). It was such groups that probably did the most to physically connect the disparate regions of South Asia by conveying material resources between them (Law 2006: 306-308; Possehl 1979: 448; Shaffer 1978: 153). However, the transmission of a set of core beliefs and principles (diffusion of ideology) may have played an even greater role in terms of socially/culturally integrating the widely dispersed and ethnically diverse (Shaffer and Lichtenstein 1989) peoples of those regions. The broad dissemination and strong reinforcement of a distinctly "Harappan" ideology (Miller 1985) is evident in the highly similar ways in which Indus Civilization peoples organized their settlements, buried their dead, used iconography, selected raw materials and fashioned their ornaments and implements. The trouble is that this form of interaction is difficult to document with a reasonable degree of spatial or temporal precision.

The exchange of material resources or finished goods (trade) is the most commonly studied form of ancient inter-regional interaction (Schortman and Urban 1992a: 236). Although this is no doubt due, in part, to the fact that it tends to be the most archaeologically visible form (and thus the easiest to document), long-distance trade is also a frequent subject of examination because of the influence it is thought to have often had on the social and political development of peoples who engaged in it (Adams 1974; Curtin 1984; Earle 1982; Kipp and Schortman 1989; Hirth 1978; Renfrew 1975; Shaikh 1991; Vikrama 2002; Webb 1974). It is an activity that is born of a society's (or of certain peoples within a society) need or desire to acquire materials/items that are scarce or absent in the region where they live. Those may range from subsistence resources and utilitarian items that are used by all of its members to exotic materials or manufactured goods that might only be used by a select few (Pires-Ferreira and Flannery 1976: 287-289). Long-distance trade provides individuals or social groups with opportunities to enhance their own wealth and/or societal status by taking control of how imported goods are distributed. The "social power" (Mann 1986) that they garner by doing this fosters social/political stratification within their society. Kenoyer (2000) argues that those people(s) who, over time, came to rule Indus Civilization cities acquired the power to do so, in large part, by controlling both access to essential raw materials and the manufacture/distribution of status-defining items.

The kinds of raw materials (imported vs. local) and the technologies (complex vs. simple) that were used in these regards varied considerably (Kenoyer 1995b: 217; Vidale and Miller 2000). Likewise variable was the nature (prestige-related vs. utilitarian) of the materials controlled and of the goods manufactured/distributed. In the next section, I discuss how imported materials (specifically rocks and minerals) of both natures were vital to the political economies of Indus Civilization cities like Harappa. However, it is not my intention to focus on *how* such materials were employed in the power strategies that facilitated the development and reinforcement of the first urbanized society in northwestern South Asia. Rather, it is to use them to ascertain *who* was involved, even indirectly, in that process.

Regions do not interact with one another, people living in different regions do. By identifying the trade networks through which residents of Harappa were importing rocks and minerals I seek to ascertain who it was that they were interacting with. Some of those people would have also belonged to the Indus Civilization. I refer to them throughout this book either as *Indus Civilization peoples* or as *Harappans* (after the type site of Harappa). The latter term is more frequently used by scholars (and is more convenient). Unless the context makes it clear, I refer to those Harappans who lived at Harappa as *residents of Harappa*. In Chapter 2, I provide details regarding the complex mosaic of regional cultures that existed across northwestern South Asia during the millennia prior to the emergence of the Indus Civilization. These peoples are referred to separately by their various regional designations and collectively as *Early Harappans* (following Mughal's [1970] convincing argument that they were all cultural antecedents to the Harappans). Also in Chapter 2, I discuss various *non-Harappan* cultures (and non-Early Harappan ones) that dwelled in regions adjacent to Indus Civilization peoples. Even though these groups were not integrated into the urbanized society of their neighbors, they were nonetheless vital contributors to it because it was from their territories that many of the resources essential to its development and maintenance were derived.

Fernand Braudel remarked (1966: 29) that the historian tends to "linger over the plain ... and does not seem eager to approach the high mountains nearby." The same could have once been said of archaeologists investigating early civilizations in the Near East and South Asia. The "highlands" (defined in Chapter 2) adjacent to the broad river valleys of those regions, while never entirely ignored, did not figure significantly in early concepts of how or where urban lifeways developed. Perceptions began to change when, starting in the 1950s, surveys and excavations in the lands between Mesopotamia and the Indus Valley – i.e., Iran, Afghanistan and Balochistan, revealed that their ranges and elevated basins were home to complex and, at places like Shahr-i-Sokhta, urbanized societies (Casal 1961; Dales 1976; Fairservis 1975; Lamberg-Karlovsky 1986; Shaffer 1978; Tosi 1982). As a result, the nature and extent of interaction between the peoples of those regions and their lowland contemporaries became an important topic of inquiry (Beale 1973). Urbanism in this part of the ancient world is now regarded to have been an extra-regional phenomenon in which highland "Middle Asia" was a significant component (Possehl 2007).

Several scholars (Algaze 1993; Dhavalikar 1995; Edens 1992; Kohl 1979) have advocated the use of "world-systems" theory (Frank 1993; Wallerstein 1974) as a model for examining trade and cultural development across a zone stretching from "the Nile to the Indus Valley in the 4th and 3rd millennium BC" (Kohl 1978: 475). In this scheme, complex and powerful "core" societies (such as the Uruk of Mesopotamia or the Indus Civilization) requiring raw materials not available in their territories are seen as engaging in exploitative, asymmetrical exchange relationships with less developed and less powerful

cultures in resource-rich "peripheries." The political-economies of those peripheral societies are viewed as being structured by this relationship with the dominant core, which controls them either directly (colonially) or indirectly (through local rulers whose power is dependent on trade goods from the core). Although world-systems analysis does constitute a holistic macro-regional model with which to examine inter-regional interaction, recent critiques (Ratnagar 2001a; Stein 1999) of its application in this part of the Bronze Age world (cited above) have found that key aspects of it – notably the assumption of a dominant core and the idea that asymmetrical long-distance trade with it imposes "structured inequalities" upon the peripheries (Ratnagar 2001a: 352), are not really borne out by the archaeological record of that region. Below are just two brief examples related to Uruk Mesopotamia.

At the site of Hacinebi in the Taurus Piedmont of southern Anatolia, a small but long-lived Uruk trading enclave was documented to have existed among the settlement's local Chalcolithic population (Stein *et al*. 1996). No evidence for inter-societal conflict or competition was recovered there that might indicate "the Mesopotamians dominated their Anatolian host community" (Stein 2002: 912). In fact, the far-flung enclave's very survival was almost certainly dependent on its members "remaining on good terms with their more powerful (in relative local terms) indigenous neighbors" (ibid.: 909). Similarly, Elizabeth Henrickson's study (1994) of Uruk relations with Chalcolithic cultures dwelling in the Zagros Mountains of western Iran indicated that the people from the politically more complex lowland society did not dominate the comparatively less complex highlanders from whom they were obtaining a range of important resources. The evidence instead suggested that the Mesopotamian "highland strategy" was one of "balanced trade and accommodation instead of brute force" (Henrickson 1994: 98).

There is good reason to believe that Harappans likewise did *not* dominate societies dwelling in the "peripheries" from which they acquired raw materials. As previously discussed, violent coercion was evidently not the means through which the widely dispersed and ethnically diverse peoples of the Indus Civilization were initially integrated into an urbanized society or how that integration was maintained for 700 years. It seems, therefore, unlikely that Harappans would have employed such a radically different and uncharacteristic strategy as that in their dealings with non-Harappan cultures in regions outside of their homeland. Moreover, even if Harappans had wanted to dominate peoples in the highlands surrounding the Indus Valley, which is where a substantial portion of the raw materials they used occurred, it is unlikely that they would have been able to do so – at least not for very long. Mountainous regions are notoriously precarious places that are often home to societies over which lowland "civilizations" have time and time again failed to establish and/or sustain any significant degree of control (Braudel 1966: 38-41). In South Asia's modern era this is exemplified in the Afghanistan-Pakistan borderlands region, where there are still today Pathan (Pukhtoon) tribes that have never been entirely subjugated despite repeated attempts by a succession of empires and nations (Hussain 2000).

When Harappans traveled outside of their homeland in order to obtain raw materials, instead of dominating and exploiting peoples of a "passive periphery" as world-systems theory would predict, they likely encountered populations of "active agents" with whom it was necessary to establish some form of mutually satisfactory exchange relationship (the quoted text is from the title of Gil Stein's 2002 review of this subject). That, at least, is the assumption I am making based on the studies and observations discussed above. I will not be attempting to test if the nature of Harappan long-distance trade did or did not conform to the world-systems model (or to any alternate model of inter-regional interaction).

To do so would require data on the control of goods and resources within its so-called "peripheries." The primary archaeological dataset that I am using (from the site of Harappa) would be considered representative of the "core." Geologic provenience studies conducted on it serve only to identify the regions from which residents of Harappa acquired rocks and minerals. Who actually controlled resources in those regions is not determinable using such data. I wish to emphasize this point because such control is sometimes assigned to Harappans without sufficient evidence. For example:

In northern Afghanistan, Harappan "control of ... highland peoples and resources may not have been as great as supposed by some" (Francfort 1985: 129). Shortughaï is an Indus Civilization outpost located in that region at the foot of the Badakhshan Mountains (Francfort 1984b). Although there are a half-dozen non-Harappan Bronze Age settlements in its vicinity (Lyonnet 1977), none have yet been excavated. Understanding the actual nature of the Harappans' relationship with the indigenous population of the region has, therefore, proven problematic (Francfort 1984a). It has been suggested that Shortughaï was established to "control the mining of lapis lazuli and other precious materials from this area" (Allchin and Allchin 1997: 168). However, other than the fact that, 1) lapis lazuli was worked at the site and that, 2) it is the nearest Indus Civilization settlement to a source of that stone (although it's still hundreds of kilometers from and thousands of meters below the actual deposits), there is really no evidence to demonstrate that Harappans *controlled* the extraction and distribution of that or any other raw material from northern Afghanistan.

The control of essential resources is a key issue in this study because, as previously discussed, the social power that groups and individuals derived from it is one of Kenoyer's (1991a) four general preconditions for the rise of urbanized, state-level society (Figure 1.2). Control of raw material sources is best supported when there are clear material culture associations with extraction areas, such as there are at chert quarries in the Rohri Hills of Sindh (discussed in Chapter 6) or at some limestone quarries near Dholavira in Gujarat (discussed in Chapter 11). Such instances are, unfortunately, very rare – the two just mentioned are the only ones that I am aware of associated with the Indus Civilization. Although an archaeological site may be situated fairly close to a raw material source, proximity alone does not demonstrate control. Of course, if a source is surrounded by sites that all belong to the same cultural "phase" (see definition p. 37) then it is reasonable to assume that peoples of that phase probably had some degree of control over it. However, the situation is not always that clear cut in most of the regions from which I show that residents of Harappa were acquiring their rock and mineral resources. In many cases, material sources are located in zones where different cultural phases came together. Other times they are found in places far from where any archaeological sites have been identified. It is for these reasons that when addressing questions related to the control and distribution of essential resources I focus on the only contexts that I am studying where a very strong case for such control can be made, which are – the different walled habitation mounds that together make up the site of Harappa. In upcoming sections of this chapter, I discuss these walled mounds and outline what I have attempted to learn by comparing the different sub-assemblages of rock and mineral artifacts recovered from them.

This study was inspired, in part, by Catherine Jarrige and Maurizio Tosi's (1981) paper "The Natural Resources of Mundigak," in which they defined the "economical space" of that Bronze Age site in southern Afghanistan by listing the probable sources for the full range of raw materials used to create the stone and metal artifacts discovered during excavations there (Casal 1961). I have adopted a similar broad-scale perspective for this project, which, on a basic level, is a straightforward effort to delineate the rock

and mineral resource catchment area or "economical space" of Harappa. However, I have tried to keep in mind an observation about studies of inter-regional interaction made by the late Prof. George Dales:

> The ultimate significance of inquiries such as this is not just to play intellectual games with bits and pieces of ancient castoffs and debris. ... What we would really like to know is the nature and extent of these relations. Just how cognizant were the citizens of each region of the peoples and cultures of the others? What degree of dependence – if any – was involved? (Dales 1968: 22).

Dales' comments serve to remind that this is also an examination of ancient inter-cultural relationships. In order to have acquired many of the resources that were essential to their urban lifeways, Harappans had to have interacted (either directly or through intermediaries) with peoples in regions that were outside of their homeland. Although the nature of those relationships cannot be clearly determined at this time, it is argued that Harappans were heavily dependent upon them because of the vital role that imported resources played in their political economy (discussed below). It is also argued that because of this, the non-Harappan cultures of the Indus Civilization's hinterlands should be regarded as among the actors that played a part, if only an indirect one, in the maintenance of Indus urbanized society. One of the aims of this study is to identify and evaluate the significance of these inter-cultural relationships by studying the trade of essential raw materials.

Nayanjot Lahiri remarked that a "qualitative leap in studies of trade [in ancient South Asia] can happen only if detailed and large-scale scientific studies on different kinds of artefacts and their raw material sources are undertaken" (Lahiri 1992: 6). Dilip Chakrabarti has expressed a similar opinion (1990: 141). Recent decades have seen some important steps in this direction. Systematic and/or archaeometric examinations of Harappan resource acquisition and long-distance trade have been conducted on marine shell (Kenoyer 1984b), subsistence goods (Belcher 1998), ceramic vessels (Méry and Blackman 1999) and stoneware bangles (Blackman and Vidale 1992). However, other than a few limited and inconclusive comparisons of copper ore sources and copper-alloy objects (which I discuss in Chapter 12), there has been a "dearth of research" on this subject involving rock or mineral artifacts (Kashyap 2005: 7). My research is, in part, an effort to rectify that situation.

### Rock and mineral artifacts and geologic provenience analysis

Of the many categories of materials that peoples exchanged in antiquity, items made from rocks or minerals (stone and metal artifacts) are perhaps the best suited to studies of inter-regional interaction and urbanism – for two reasons. Firstly, both prestige and utilitarian (designations discussed below) rock and mineral goods were vital to the *political economies* ("the material flows of goods and labor through a society, channeled to create wealth and to finance institutions of rule" – Earle 2002: 1) of complex hierarchical societies like the Indus Civilization. Secondly, such artifacts are particularly well-suited to studies aimed at reconstructing resource acquisition networks by identifying the place of origin, or *geologic provenience*[3], of the raw material from which they are composed.

Exotic (rare) rocks and minerals and the items fashioned from them are among the most important kinds of *prestige* goods. Such goods were used as objects of wealth as well as markers of status, identity

3) as opposed to an artifact's *archaeological provenience* – meaning the specific archaeological context from which it was recovered, or *provenance* – its history subsequent to its recovery (see Appendix 1.1).

and authority (Brumfiel and Earle 1987; Helms 1993; Hayden 1998; Kenoyer 2000; Trubitt 2003). Although most Harappan stone and metal artifacts of this nature are notable for their small size, I argue later (in Chapter 11) that certain large and heavy objects like limestone ringstones were likely prestige-related. In terms of the political economies of early urban societies like the Indus Civilization, the acquisition of "exotic goods must be seen in the same ways as the accumulation of grain or livestock" (Kenoyer 1991a: 345). Using wealth and influence gained by the control of those goods, individuals or groups governing a society could finance and reinforce institutions of rule. However, rulers that relied too heavily on such a "wealth finance system" (Earle 1991) might find their positions compromised by an interruption in the flow of exotic materials.

Harappans would have required many different kinds of *utilitarian* stone and metal implements in order to carry out innumerable common, day-to-day tasks associated with living and working in an urbanized society. Having reliable access to the resources needed to make them would have been a significant concern for those dwelling at settlements in the Indus Valley proper as there are few sources of stone in that region (there are none at all within 120 km of Harappa – discussed in Chapter 2). The need would have been particularly acute at Harappa itself, which was both a center for numerous craft industries and home to a large urban population. Agate nodules brought to the site from Gujarat (Chapter 8) could not have been transformed into beads with high prestige value unless a range of utilitarian stone was also available to make the different tools needed for chipping, perforating and grinding them. Enough surplus grain to support an urban population could be produced on alluvial plains that surrounded the city, but the heavy sandstone-quartzite querns and mullers needed to process it could be acquired only from geologic formations hundreds of kilometers away (Chapter 5). Monica Smith showed how the demand for "ordinary goods" played a major role in the "development, success, and long-term viability of regional trade networks" during the Early Historic period of central India (Smith 1999: 109). The need for "ordinary" stone by people dwelling in the rock and mineral resource-poor Indus Valley probably had a similar influence on regional trade in that part of South Asia during the Bronze Age. Controlling utilitarian goods may have even been an important and, in ways, more stable (as compared to a wealth finance system) political-economic strategy for ruling elites in the ancient world (Aoyama 2001; D'Altroy and Earle 1985; Schwartz *et al.* 1999; Wright 1984). Had Harappan elites desired to control "ordinary" rock and mineral resources for their own benefit (i.e., to enhance their own wealth and influence), then the situation in the Indus Valley would have afforded them an opportunity to do that.

It was probably the case that those who governed Indus Civilization cities derived their power to do so, in part, through the control of both "exotic" and "ordinary" goods. However, with a few exceptions, I do not dwell too closely on either the prestige or utilitarian natures of the artifacts examined in this book. As previously stated, it is not my intent to focus on the particulars of how Harappans used rock and mineral resources in their political power strategies. Also, what constitutes a prestige good versus a utilitarian one is not always that clear or absolute (for a detailed discussion of this matter see Smith 1999: 113-114). For the purposes of what I am trying to accomplish, it is important to recognize that stone and metal goods of *both* natures were essential to the development and functioning of the Indus Civilization and its cities. Furthermore, at a settlement deep within the Indus Valley like Harappa, a rock or mineral artifact's mere presence indicates that someone once decided that it was worth the time and effort to transport it (or worth the expense to acquire it after it had been transported) hundreds of kilometers to the site. In this regard, there are

no unimportant artifacts in this material category, in spite of how mundane some may seemingly be. It is for these reasons that I examine, in one way or another, every rock and mineral variety within Harappa's artifact assemblage. This all-inclusive approach reduces the need to draw sharp distinctions between prestige and utilitarian materials. Both were essential and both are examined. Most importantly, this approach provides the broad perspective required to thoroughly address this study's main question: With whom were the residents of Harappa interacting?

In the absence of historical accounts of trade or other forms of inter-regional interaction, geologic provenience analysis can provide compelling evidence that a link (however indirect) once existed between the ancient inhabitants of a region where a stone or metal artifact entered the archaeological record and those in the region where the raw material the artifact is composed of originated. The soundest provenience determinations are ones based on analyses of artifacts composed of unadulterated rock or mineral rather than processed metal, which could contain metal from multiple sources as well as various alloys and additives. With unadulterated stone, "specific types of raw materials can be related to an objective geologic reality that is derived from natural (as opposed to cultural) processes" (Odess 1998: 419). It is for this reason that the artifacts favored for analysis in this study were raw materials or manufacturing debris. Such artifacts were also favored because they were probably used and discarded during roughly the same period that they were originally acquired and, thus, are likely to represent contemporaneous links between different regions. Finished items (especially ornaments) might have been traded or passed down for decades or even centuries prior to entering the archaeological record.

Archaeologists around the world have used a wide variety of techniques and instrumentation in efforts to identify the geologic sources of an even wider variety of stone and metal artifacts (Henderson 2000; Lambert 1997; Pollard and Heron 1996; Rapp 2002). In Chapter 3, the strategies and methods employed in this study are detailed in full. To date, over 2100 geologic provenience determinations for eight main varieties of stone or metal artifacts from Harappa have been generated along with nearly 120 for artifacts from twelve other sites. With this substantial new database on rock and mineral resource acquisition, it is possible to examine inter-regional interaction during the initial manifestation of urbanized society in South Asia in an unprecedented level of detail.

Although it is an extra-regional phenomenon, "urbanism plays itself out most visibly on the local" level (McIntosh 1999: 68). In northwestern South Asia, the site of Harappa is the optimal locale to study it. Harappa's stratigraphic sequence encompasses the development, existence and decline of the Indus Civilization and, because it was continuously a center for numerous craft industries from the time it was established, the abundant remains of rock and mineral resources are found at each stage of its existence. These remains, which have been documented by the Harappa Archaeological Research Project, constitute a dataset that is unparalleled in the region. In the next section, I introduce the site and the dataset.

## HARAPPA

The focal point of this book is the archaeological site of Harappa, located in District Sahiwal, Punjab Province, Pakistan (Figure 1.3). In this section, I discuss the site's general location and layout; provide an overview of the archaeological investigations that have taken place there; introduce its rock and mineral assemblage, which is the primary dataset for this study; and review the site's chronological / cultural sequence in detail.

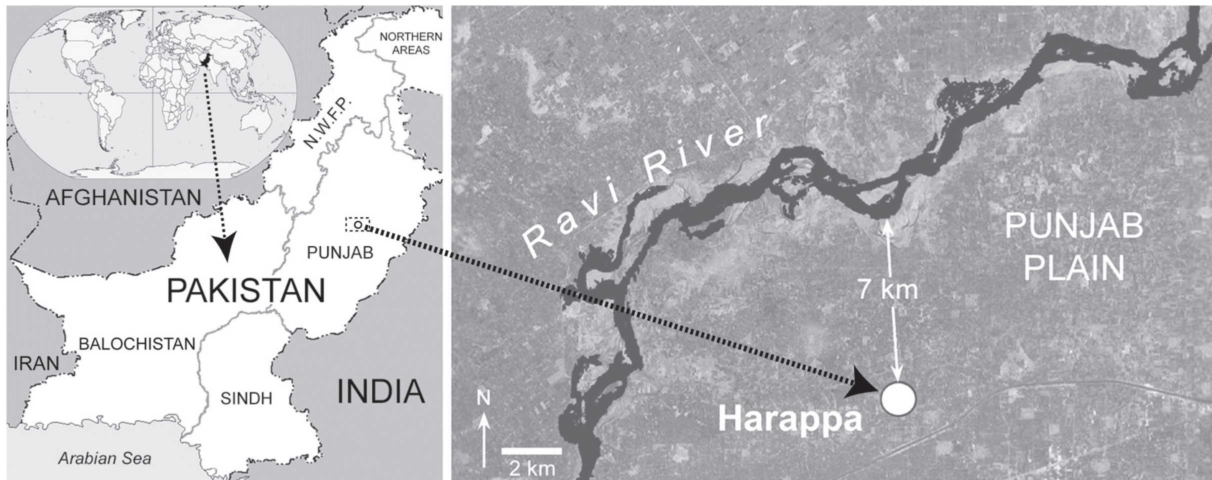


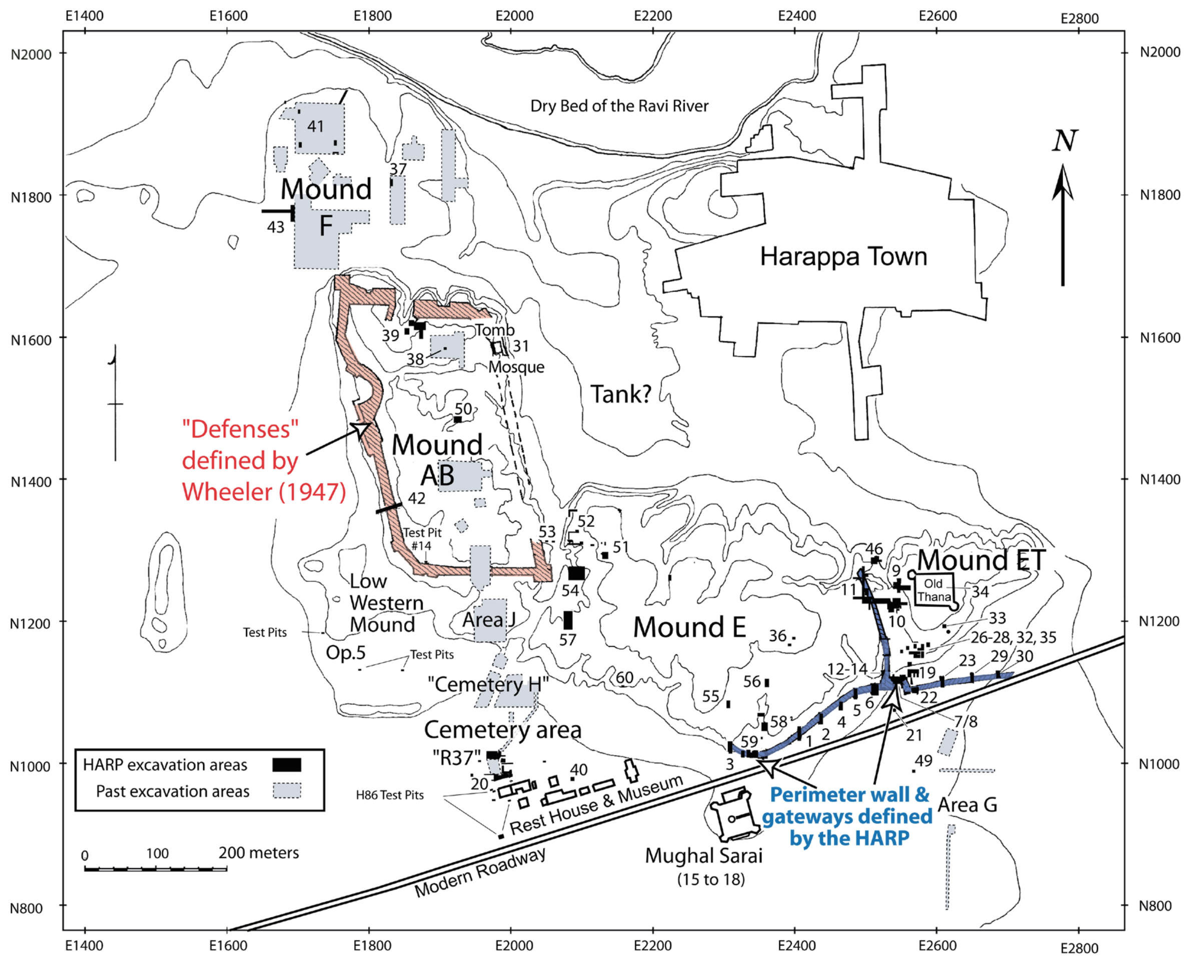

**Figure 1.3** Harappa's location today (world map adapted from Wandrey and Law 1998).

### General location and layout

Harappa was founded upon an alluvial terrace in the center of the fertile but rock and mineral resource-deficient Punjab Plain of the upper Indus Basin around the mid-fourth millennium BC (full details relating to the site's geologic and geographic contexts are provided in Chapter 2). By the mid-third millennium BC, the settlement had grown to become one of the largest Indus Civilization cities – covering an area of perhaps 150 hectares (ha) at its greatest extent (Dales and Kenoyer 1989a: 72). At that time, the site consisted of several distinct habitation areas, the mounded remains of which rise as high as 17 meters above the surrounding plain (Figure 1.4). The modern town of Harappa sits atop one of these mounds in the northeast portion of the site. The Ravi River is presently situated seven kilometers to the north (Figure 1.3 *right*) but *may* have been closer in Harappan times. Marking the northern edge of Harappa is an abandoned channel of the Ravi (Figure 1.4), which fills with water during the summer monsoons (Belcher and Belcher 2000).

### History of discovery and research

The site of Harappa was "discovered" in 1829 when an antiquarian named Charles Masson camped near the remains of a "ruinous brick castle" while journeying through the Punjab (Masson 1844: 453). Unfortunately Harappa's bricks also attracted the attention of British railroad engineers who, seeking a source of ballast in the stone-free Punjab Plain, systematically plundered them in the late 1850s for the building of the Lahore-to-Multan line (Possehl 1999: 51-52). This destroyed most of the site's post-1900 BC occupational strata and greatly disturbed much of that belonging to the Harappan Period (ca. 2600 to 1900 BC). In spite of the damage caused by "brick-robbing," Sir Alexander Cunningham conducted the first limited excavation at Harappa in 1873 (Cunningham 1875). He also published a plan (ibid.: Plate XXXII) on which the different mounds and areas of the site were assigned letter designations that are still used today (hence mounds AB, E, ET and F on Figure 1.4). During the 1920s and 30s, large-scale excavations were undertaken by Rai Bahadur Daya Ram Sahni (1921, 1926, 1927) and Madho Sarup Vats (1933, 1935, 1936). These form the basis of the "site report" – Excavations at Harappa (Vats 1940). Although several follow-up digs took place over the next few decades, the results remain largely unpublished (Possehl 1991). Important exceptions are Rafique Mughal's excavations in the cemetery area (Mughal 1968) and Sir Mortimer Wheeler's single excavation season of 1946 (Wheeler 1947) during which he defined the walled "defenses" of Mound AB and, in a deep sounding, discovered a pre-Indus



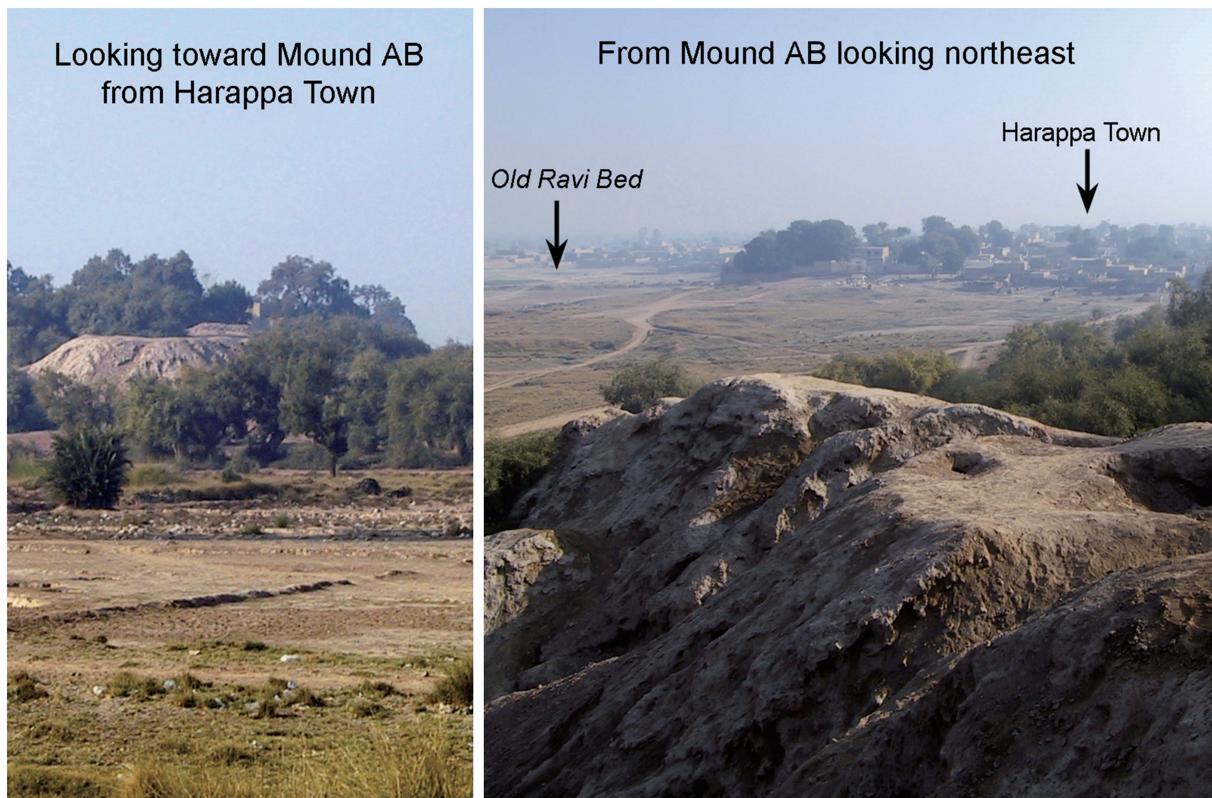




**Figure 1.4** Harappa – site plan and views toward and from the mounds.
This and all subsequent site plans in the dissertation are modified from Meadow *et al*. 2001: Figure 2.

Civilization occupation at the site. The areas where excavations prior to 1986 took place are noted in gray on the site plan (Figure 1.4).

In collaboration with the Department of Archaeology and Museums, Government of Pakistan, a program of sustained excavation and research was initiated at Harappa in 1986 – first as a University of California-Berkeley Project under the direction of the late Prof. George Dales and Dr. J. Mark Kenoyer (Dales and Kenoyer 1986b, 1988, 1987, 1989b, 1990b) and then reorganized as the Harappa Archaeological Research Project (HARP) under the direction of Drs. Richard Meadow and J. Mark Kenoyer (Meadow and Kenoyer 1992, 1993; Meadow *et al* 1994, 1995, 1996, 1997, 1998, 1999, 2001). I hereafter use the acronym "HARP" when referring to the post-1986 excavation program. Marked in black on the site plan (Figure 1.4) and labeled by trench number are the HARP excavation areas.

One of the stated objectives of the HARP is the study of Harappa as a "discrete urban phenomenon" (Dales 1991: 1). Now, after 22 seasons of detailed, question-oriented excavation and research, a great deal is known about how the nature of this particular settlement and the culture of the people living at it transformed over time. These transformations have been documented in the form of changes in site size, architecture, artifact types and artifact forms (Clark 2007; Meadow and Kenoyer 1997, 2001, 2005). Successive innovations in craft technologies have been detected (Kenoyer 1992, 1995b, 2005a; Kenoyer and Miller 2007; Miller 1999) as well as evidence for shifting strategies of faunal (Belcher 2003; Meadow 1991; Miller 2004) and plant exploitation (Weber 1999). Although as yet undeciphered, it is now possible to trace the development and changing uses of the Indus script at Harappa (Kenoyer 2006; Kenoyer and Meadow 1996). Collectively these studies provide a rich body of contextual information that can be used to inform research projects like this one, which should be considered as another aspect of the ongoing effort by the HARP to understand urbanism at Harappa and in ancient South Asia.

### Harappa's rock and mineral artifact assemblage

Harappa was a center for many different kinds of craft activities involving stone or metal (Kenoyer 1992,




**Figure 1.5** Surface survey on Mound E and some of the stone and metal artifacts recovered.

1995b, 2005a). To appreciate this one need only to walk across its mounds and look down toward one's feet. Numerous varieties of rocks and minerals (in the form of both finished items and production debris) are evident on the site's surface. They are gathered by the handful during surface surveys (Figure 1.5) and are equally abundant as underlying strata are exposed. By the end of the 2004 field season, some 56,350 stone or metal artifacts had been recovered and tabulated by the HARP. My aim has been to make full use of this immense dataset by examining it at multiple scales.

There are certain questions relating to how rock and mineral resources were used and controlled by residents of Harappa that can be addressed only by examining the assemblage on a very broad scale. For example: Was there, in fact, "hardly any major change in the types of raw materials used between the early and mature Harappan" periods as Chakrabarti (1998: 51) has posited? Were groups of Harappans dwelling in different habitation areas (mounds) acquiring the same basic suite of rock and mineral resources? The broad perspective needed to address these kinds of questions is achieved by treating the entire assemblage as a single entity that is made up of multiple "elements" (different rock and mineral varieties), which may or may not vary over space and time. This scale of examination is employed in Chapter 4, when all stone and metal artifacts at Harappa are categorized by material variety and their spatial and temporal distribution patterns are collectively observed. Provenience studies of specific rock and mineral varieties, which are presented in chapters 5 through 12, constitute examinations of the dataset at finer scales. The summary of the individual provenience study results with assemblage spatial and temporal distribution data that is presented Chapter 13 represents a return to a broader scale.

This study is possible because of the well-planned excavation strategy of the original HARP directors who posed many of the same questions I am now investigating and saw to it that all stone and metal encountered during surveys and excavations were collected and contextual information for each individual item was meticulously recorded. When considered in relation to Harappa's increasingly well-understood chronological / cultural sequence (discussed next) this immense, well-documented dataset becomes a powerful tool for examining resource acquisition and inter-regional interaction over time.

### Harappa's chronological / cultural sequence

Other Indus Civilization cities have been excavated but none have a chronological sequence that, being based on over 100 radiocarbon determinations (Meadow and Kenoyer 2005: 208-209), is as temporally secure as the one at Harappa. These $^{14}C$ dates, in combination with a close adherence to the principles of stratigraphic excavation (Kenoyer 1992) and diachronic studies (Dales and Kenoyer 1991; Kenoyer and Meadow 1999, 2000;

**Figure 1.6** Harappa periodization and chronology (after Meadow and Kenoyer 2001)

| | | |
|---|---|---|
| **Period 1** | Ravi (Early Harappa) Phase | > 3300 BC - ca.2800 BC |
| **Period 2** | Kot Diji (Early Harappa) Phase | ca.2800 BC - ca.2600 BC |
| **Period 3A** | Harappa Phase A | ca.2600 BC - ca.2450 BC |
| **Period 3B** | Harappa Phase B | ca.2450 BC - ca.2200 BC |
| **Period 3C** | Harappa Phase C | ca.2200 BC - ca.1900 BC |
| **Period 4** | Harappa/Late Harappa Transitional | ca.1900 BC - ca.1800 BC? |
| **Period 5** | Cemetery H (Late Harappa) Phase | ca.1800 BC? - <1300 BC |

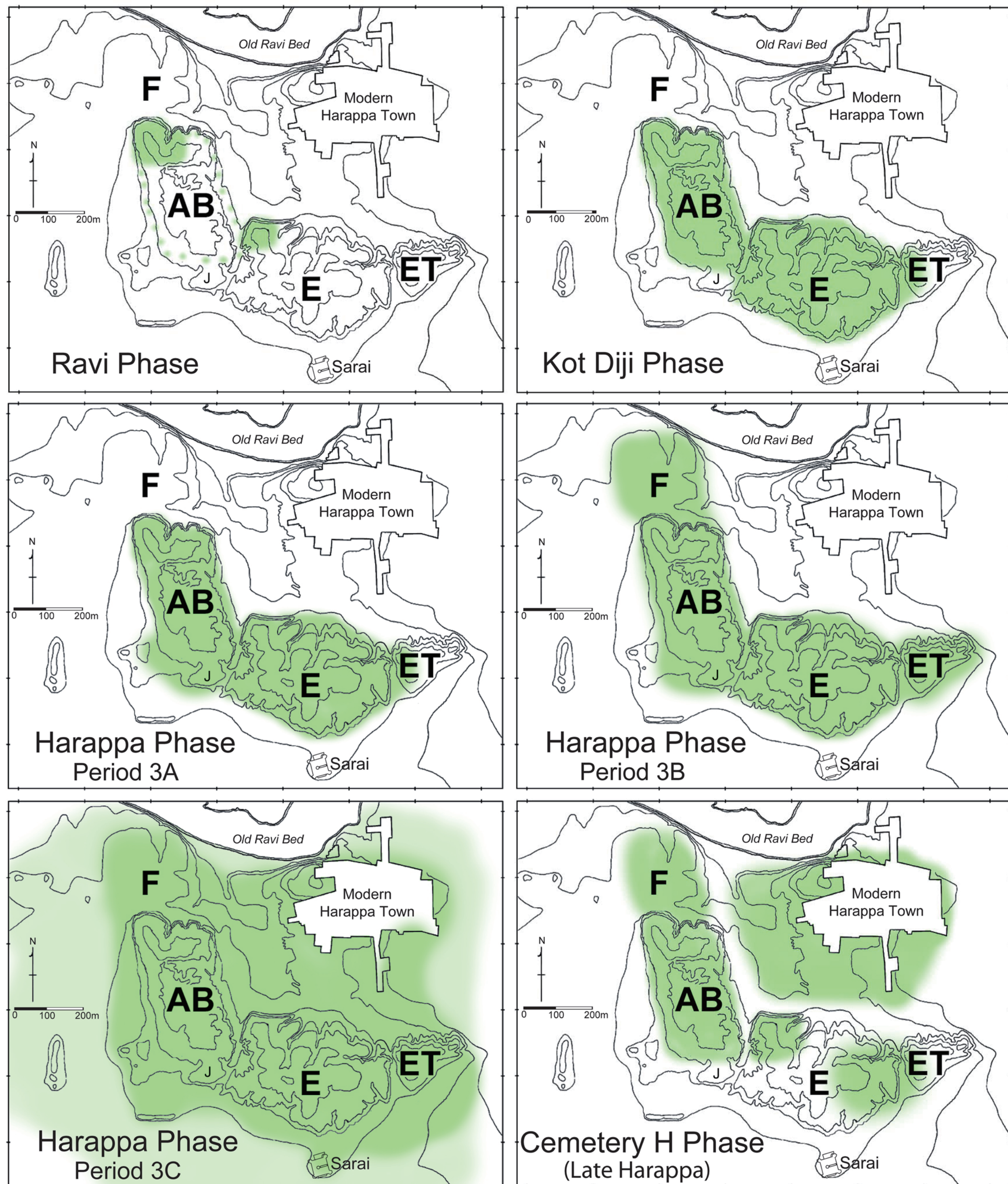



**Figure 1.7** Settlement growth and decline at Harappa ca. 3300 to <1300 BC

Meadow and Kenoyer 1994, 1997, 2005, 2008) of architecture, artifact forms and material culture assemblages, have enabled HARP excavators to reconstruct the site's cultural history in great detail. Five main periods of pre/proto-historic occupation have now been delineated that extend roughly from the mid-fourth millennium BC to the mid-second millennium BC (Figure 1.6). This cultural sequence encompasses the development, existence and later-stage transformations of the Indus Civilization. There are two *Early Harappan* (a chronological / cultural designation that are discussed below and in Chapter 2) phases – the pre-urban *Ravi Phase* (Period 1) and the incipient urban *Kot Diji Phase* (Period 2). These are followed by the fully urban *Harappa Phase* (Period 3 with sub-periods 3A, 3B and 3C). This period/phase

is equivalent to the extra-regional manifestation of the Indus Civilization and is often referred in the literature as the "Mature" Harappan Period. Here, however, I simply use the term "Harappan" when referring to this phase at the site and in the region. The protohistoric sequence closes with a short transitional phase (Period 4) and the late/post urban *Late Harappa Phase* (Period 5).

The settlement of Harappa underwent significant transformations in terms of size and organization during its two millennia-long protohistoric cultural sequence (Figure 1.7). In the sub-sections that follow, I outline these changes (refer to figures 1.3 and 1.6 as they are discussed) and review the cultural attributes characteristic of each the site's phases and sub-phases. These overviews are intended to be site specific. In Chapter 2, I discuss in detail the regional and extra-regional cultural phases to which residents of Harappa belonged.

***Ravi Phase – Period 1 (> 3300 BC - ca.2800 BC)***

The initial occupation (Period 1) at Harappa has been designated the "Ravi" Phase by Kenoyer and Meadow (2000). It is presently known from Trench 39 on the northern end of Mound AB and from a very limited exposure in Trench 52 on the northwestern corner of Mound E. The earliest relevant $^{14}$C dates for this period "are not older than c. 3300 calBC" (Meadow and Kenoyer 2005: 209). These dates, however, were obtained from strata that, at the time, would have constituted the northern fringe of the settlement. It is, therefore, quite possible that earlier, more deeply buried levels exist toward the center of the site (ibid.), which is estimated to have been around seven to ten hectares in size (Kenoyer and Meadow 2000: 56). Two sub-periods/phases (1A & 1B) are defined based mainly on changes in ceramic technology that took place over the course of what appears to have been an uninterrupted cultural sequence. The polychrome ceramics used during the earlier part of the Ravi Phase (Period 1A) were all built by hand. Wheel-thrown pots appeared and gradually increased in number during the latter portion of the phase (Period 1B), which merges into Period 2 at around 2800 BC. The transition from 1A to 1B is not well-demarcated stratigraphically. For this reason and because the total exposure for this period is very limited, the rock and mineral artifacts recovered from Ravi Phase levels are, for the purposes of this study, treated as a single, undivided sub-assemblage.

Many cultural features that are hallmarks of the Indus Civilization were already present, at least in rudimentary form, at the Ravi Phase village of Harappa. For example, Ravi Harappans constructed their wattle and daub and mud-brick dwellings with walls that were oriented in the cardinal directions (Meadow and Kenoyer 2001: 22-23), just as later baked-brick architecture would be at this and other Indus Civilization sites. Many of the graphic symbols they inscribed on their ceramics appear to be precursors to the Indus script (Kenoyer and Meadow 1996; Meadow and Kenoyer 2008). Although we cannot be certain until more extensive excavations are conducted, the Ravi Phase village of Harappa already *may* have been organized into distinct habitation areas – Mound AB and Mound E (Kenoyer and Meadow 2000). Most significantly, certain Ravi Harappans were acquiring raw materials (marine shell and different varieties of stone) from very distant sources and, using complex craft technologies, transforming them at the site into items that signified wealth and social status (Kenoyer and Meadow 1999, 2001; Kenoyer 2005a).

Developments similar to the ones above probably took place at villages across northwestern South Asia during the fourth and first half of the third millennia BC. Rafique Mughal characterized the various regional cultures with such antecedent Indus Civilization traits as "Early Harappan" (Mughal 1990a). At Harappa, this apt designation is applied to the site's first two cultural phases and to the period during which they existed.

### *Kot Diji Phase – Period 2 (ca.2800 BC to 2600 BC)*

There is no discernible hiatus between Ravi Phase strata and that of the subsequent "Kot Diji" Phase (Period 2) in the two trenches (39 and 52) where they are both present. Ravi-type ceramics were gradually replaced by Kot Dijian forms (first defined at the site of Kot Diji in northern Sindh – Khan 1965) sometime around 2800 BC. There are a number of trenches in which Period 2 remains directly overlay natural soil, which indicates the settlement had expanded into new, previously unoccupied areas. Harappa was now clearly organized into two distinct mounds – AB and E. The latter included a portion of what would become Mound ET. The size of the occupation during this phase is estimated to have been greater than 25 ha (Meadow and Kenoyer 2001: 24).

The cultural entity that residents of Harappa belonged to during Period 2 – the "Kot Diji" culture, extended far beyond the site and its immediate hinterland of the Punjab Plain (discussed in Chapter 2). Many have argued that "Kot Dijian" society represents an incipient stage of urbanization in northwestern South Asia just prior to the emergence of the Indus Civilization (Allchin and Allchin 1997; Durrani *et al.* 1995b; Flam 1981; Meadow and Kenoyer 2001; Mughal 1990a). Discoveries made during HARP excavations of Period 2 levels at Harappa have lent support to those assertions (Meadow and Kenoyer 1999, 2001: 23-26, 2005, 2008). It is now known that the massive city walls surrounding mounds AB and E had their origins in the Kot Diji Phase. Early Harappan revetment walls, although smaller than later ones, were built using mud-bricks fashioned in roughly the same dimensions (1:2:3 or 1:2:4 ratio) that would become the standard for bricks across the Indus Civilization. These structures probably served a variety of purposes (Belcher and Belcher 2000: 705; Meadow and Kenoyer 1994: 468) including helping to stabilize architecture, demarcating social and/or administrative boundaries, and providing protection against aggressors (human or animal) and seasonal flooding. Significantly, the construction of perimeter walls indicates that Kot Dijian Harappans had a concern for controlling access into their settlement. It also demonstrates that they had the ability to organize labor on the scale necessary to build and maintain monumental public works (Dales and Kenoyer 1992: 62). Emerging administrative sensibilities during this period are likewise suggested by the discovery of stamps seals and a standardized cubical stone weight – technologies indicative of the need to document ownership, assess value and facilitate transactions in an increasingly complex socio-economic setting. The use of an early form of the Indus script by Kot Dijian residents of Harappa points to advancements in communication while the diversification of specialized craft industries is thought to be "linked to the emergence of a more highly differentiated society" (Meadow and Kenoyer 2005: 211). The wide variety of non-local raw materials recovered in Kot Diji levels points to active long-distance exchange, which was no doubt facilitated by the advent of bullock cart transportation (Kenoyer 2004). Faunal studies (Belcher 1991, 1998, 2003) have revealed that the importation of salted fish from the Arabian Sea coast (over 800 km distant) began during this period. All of these discoveries paint a picture of a settlement and a society that was markedly more complex than it had been during the Ravi Phase. When they are considered in relation to developments taking place on the regional level (discussed in Chapter 2) and those evident in the site's subsequent cultural phase (discussed next), a characterization of the Kot Diji Phase at Harappa as incipient urban is clearly appropriate.

### *Harappa Phase – Period 3 (2600 BC to 1900 BC)*

In stratigraphic levels dating to around 2600 BC, ceramics and other artifacts characteristic of the Kot Diji phase underwent a "gradual transformation" into what is commonly thought of as the "Harappan" material culture assemblage of the Indus Civilization

(Meadow and Kenoyer 2001: 25). This transition marked the beginning of the fully urban "Harappa" Phase (Period 3) at Harappa. The first constructions using baked-bricks appeared at this time and there was a "strong continuity in architectural orientation between the earlier city walls of Period 2 and the massive city walls of Period 3" (Meadow and Kenoyer 2005: 224). At several excavated Indus Civilization sites in other regions such as Kot Diji in Sindh (Khan 1965), Nausharo in Balochistan (Jarrige 1989), Ghandi Umar Khan in the North-West Frontier Province or NWFP[4)] (Ihsan Ali *personal communication* 2004) and Kalibangan in Rajasthan (Thapar 1973), there are apparent localized discontinuities (burnt or sterile layers) between the remains of Early Harappan and Harappan Period occupations. This likely indicates that, not surprisingly, the emergence of the Indus Civilization occurred in different ways in different parts of northwestern South Asia. At Harappa in the Punjab, however, it is clear that the cultural roots of the site's Period 3 residents were local, emerging directly and without disruption from the preceding Kot Diji Phase.

The Indus Civilization existed for approximately 700 years. Although it exhibited a striking degree of diachronic continuity in terms of its general material culture attributes, this society underwent significant cultural developments during that time. At Harappa, these are evident as changes in site size, organization, architecture, artifact forms, motifs and technologies. Based on these documented developments and supported with $^{14}$C dates, three chronological sub-periods of the Harappa Phase have been defined: *Period 3A* from 2600 to 2450 BC; *Period 3B* from 2450 to 2200 BC; and *Period 3C* from 2200 to 1900 BC.

*- Period 3A*

Period 3A is the least well-understood of the Harappa Phase sub-periods due the fact that it is deeply buried. It has been possible to determine through deep soundings across the site that the area of occupation at this time remained more or less confined to mounds AB and E (Area J just south of Mound AB was *perhaps* also occupied by this time or soon after). The portion of mound E that during the Kot Diji Phase had extended short a way into what would later become mound ET was truncated by the massive city walls built during Period 3A over the smaller ones of Period 2 (Meadow and Kenoyer 1997). Although the "Harappan" material culture assemblage was fully developed at this time, many aspects of it (ceramics, seals, writing, figurines etc.) would continue to undergo stylistic and functional changes as Period 3 progressed. Toward the end of this sub-period, the city, or at least certain parts of it, endured a period of "decay and disrepair" (Kenoyer 1991b: 55). Excavations of 3A levels on the south side of Mound E revealed clogged sewer drains that had overflowed into the streets, the remains of discarded animal carcasses and a general deterioration of the city wall and gateway (ibid.).

*- Period 3B*

Period 3B appears to have been a time of significant renewal, growth and innovation at Harappa (Meadow and Kenoyer 2000: 337). The deteriorating architecture on the southern side of Mound E was rebuilt at the beginning of this sub-period (Meadow and Kenoyer 1997: 140) and at least two new habitation areas – Mound ET and Mound F, were incorporated into the settlement. Mound ET has been characterized as a "suburb" (Kenoyer 1998: 55) that grew directly east from Mound E. Around the beginning of Period 3B, the city wall of

4) On April 15th, 2010 the North-West Frontier Province was officially renamed Khyber-Pakhtunkhwa Province. Unfortunately, the maps prepared for this book could not be revised before it went to press. Therefore, for internal consistency, the name North-West Frontier Province and the initialism NWFP will be retained in the text.

E was extended to encircle ET and a gateway was constructed at the southern juncture of the two mounds (Meadow and Kenoyer 1997: 143). The habitation area designated Mound F was built upon the remains of Period 3A garbage debris that had been dumped into a depression left by the mining of clay to build the walls and houses of Mound AB, which lay directly to the south (Meadow and Kenoyer 2005: 211-212). The massive wall surrounding Mound F and the large structure built within its confines called the "granary" (although there is no real evidence that building served this purpose) were first constructed in Period 3B (Meadow and Kenoyer 2008). Coinciding with this period of urban renewal and expansion are communication innovations in the form of tiny (≈ 1 cm in length) steatite "seals" (tablets) incised with the Indus script and small (≈ 2 to 3 cm) molded faience and terracotta tablets bearing writing and ritual scenes (Meadow and Kenoyer 2000).

*- Period 3C*

Period 3C is the best studied of all the time periods at Harappa due to the fact that its extensive remains were made easily accessible when they were laid bare by brick-robbing activities. The most conspicuous and reliable material indicator of this sub-period is a distinctive type of ceramic known as a pointed-base goblet or "PBG." These mass-produced and evidently disposable drinking vessels are found in enormous quantities in every area of the site. When examining the records of past excavations at Harappa (for which stratigraphic control was generally poor), it is possible to be fairly confident that levels equivalent to Period 3C (or later disturbed deposits) are being reported when PBGs are mentioned or appear on a plan or section drawing. HARP excavators have determined that two other artifact types – rectangular steatite seals bearing the Indus script only and glazed faience geometric seals, were also used exclusively during this sub-period (Meadow and Kenoyer 2001: 27). Artifacts associated with the Bactria-Margiana Archaeological Complex (BMAC) of southern Central Asia likewise appear in the archaeological record at Harappa during Period 3C (Meadow 2002; Parpola 2005). The timing of these finds, which are both indicative of the cosmopolitan nature of the site and important evidence for long-distance interaction with cultures originating to the northwest of the Indus Valley region, is wholly consistent with the established BMAC chronology (Hiebert 1994).

Each major mound at Harappa was settled by Period 3C, including the one over which the modern town of Harappa is built. In addition, remains have been encountered during past excavations, HARP operations (trenches, test pits, corings) and modern construction projects (sewers, wells, roads) away from the mounds that indicate the settled area during this period extended well beyond the parts of the site that are visible above the alluvial plain. Trenches sunk by M.S. Vats (1940: Chapter V) in Area G south of Mound ET revealed fragmentary structures and burials in association with numerous PBGs. Period 3C remains were also encountered during HARP excavations beneath the Mughal Period (ca. 16th century AD) caravansarai, which is situated just south of Mound E's southern gateway (Meadow and Kenoyer 1993: 14). The total area occupied during this sub-period is estimated to have been 150 ha or more (Dales and Kenoyer 1989a: 72).

Kenoyer hypothesized (1993: 186-187) that overcrowding during Period 3C may have led to "a breakdown of civic order" – at least in certain parts of the city. For example, the south side of Mound E was an active neighborhood at this time as indicated by extensive deposits filled with PBGs and numerous kinds of craft production debris. However, degrading architecture, construction re-using broken bricks, structures encroaching into public thoroughfares and clogged sewers point to a greatly diminished emphasis on civic maintenance (similar to that evident at the end of Period 3A) in this part of the city. In contrast, areas like Mound AB and Mound

F were comparatively well-maintained during Period 3C and, based on a number of material indicators, are thought to have been "inhabited by prosperous individuals" (Meadow and Kenoyer 2005: 212). Such diachronic fluctuations and synchronic disparities in the relative prosperity of different neighborhoods (zones, quarters, barrios, etc.) are typical of long-lived urban centers. Even so, the overcrowding and lack of civic control evident at Harappa during Period 3C, while not yet site-wide phenomena, may have been harbingers of things to come.

***Transitional and Late Harappa Phases – Periods 4 & 5 (1900 BC to <1300 BC)***

South Asia's first era of urbanization gradually began to come to an end around 1900 BC. For reasons not yet entirely understood, but which probably relate in some part to changes in river courses and a general demographic shift eastward (Possehl 1997c), the interaction networks that had culturally and economically integrated peoples across the Greater Indus region for seven hundred years diminished and several localized "Late Harappan" cultures emerged (discussed in Chapter 2). In the upper Indus Valley, the Late Harappan Period is represented by the "Cemetery H" culture. At Harappa, where it was first defined (Vats 1940: Chapter IV), this cultural phase is designated as Period 5 and seems to have been "firmly established" by 1700 BC (Meadow and Kenoyer 2005: 209). A transitional phase (Period 4) between the Harappa and the Cemetery H phases has been designated but is not well-defined temporally due to the poorly preserved nature of post-Period 3C deposits. However, excavations in the areas where small amounts of undisturbed strata from periods 4 and 5 remain (Trench 43 on Mound F and Trench 38 on Mound AB) seem to indicate that the transition did not involve the abandonment, invasion or destruction of the city. In fact, important continuities are evident. Many established architectural and craft traditions continue through the last two periods (Kenoyer 2005b) and there are indications that users of "Late Harappan style pottery were living together with people using Harappan style pottery during the Period 4 transition" (Meadow and Kenoyer 2001: 34). Most significantly, the skeletal remains of Cemetery H Phase Harappans show "clear biological affinities with the earlier residents of Harappa" (Kennedy 2000: 312).

Continuities notwithstanding, the Late Harappa Phase represented a dramatic cultural transformation at Harappa (Kenoyer 2005b). Very different burial practices and new highly distinctive artifact styles and iconography are associated with the Cemetery H culture. The shell-working industry at the site seems to have come to an end (possibly due to the break down of long-distance trade routes to the south) while early glass-making technology and new innovations in bead-drilling appeared (ibid.). Barley became the dominant cereal crop (whereas wheat had been dominant in the Harappa Phase) and there was a large increase in the use of summer-cropped plants during the Late Harappan Period (Weber 1999, 2003). The need for the communication and administrative technologies such as the Indus script, cubical stone weights and stamp seals appears to have ceased despite indications that the site remained densely populated (Kenoyer 2005b). Judging by the distribution of Cemetery H ceramics on the site's surface and test pits made in the vicinity of Harappa town, it is estimated that an area up to 100 ha may have been occupied during Period 5. A terminal date for this phase at Harappa is, again because of the brick-robbing, difficult to estimate but it was most likely prior to 1300 BC (ibid.).

Because the total excavated area for periods 4 and 5 is so small (even more so than for Period 1), the rock and mineral artifacts recovered from these levels are treated as a single chronological sub-assemblage (Period 4/5) for the purposes of this study.

### Non-habitation areas at Harappa

I conclude this introduction to Harappa with a few brief remarks regarding areas of the site that were not inhabited. Nearly 7% of the rock and mineral artifacts recovered during HARP excavations and surface surveys came from such contexts.

An extensive cemetery area is located in the southwest corner of the site. A series of Late Harappan Period pot burials and graves were excavated in "Area H" (hence Cemetery H), immediately to the south of Mound AB and Area J (Vats 1940). Farther to the south is another group of interments in an area designated "R37." This Harappa Phase cemetery was the focus of HARP excavations during the late 1980s (Dales and Kenoyer 1989a) and several of the stone and metal artifacts that are the subjects of detailed geologic provenience studies are well-dated burial items associated with individuals in these graves.

A great deal of rock and mineral debris has been recovered from areas surrounding the site where Harappans dumped their garbage. One of the most extensive of these areas is known as the "Low Western" Mound, just off the southwest corner of Mound AB. Test pits sunk to natural soil there encountered no structures – only Harappa Phase refuse (Dales 1991: 187, 190). Nearby, a thick layer of Period 3C dump debris overlies Cemetery R37.

Although no artifacts have been recovered there, it is important to note the broad, flat, featureless area at the center of Harappa, which *may* be where a large water tank/reservoir (now filled in) was located (Kenoyer *personal communication*). Such water management structures have a long history in South Asia (Whitcombe 1982), going back as far as the Harappan Period at the sites of Dholavira (Bisht 2005) and Lothal (Leshnik 1968).

In the next section, I outline the three lines of inquiry pursued in this book.

## THREE LINES OF INQUIRY

This research project was designed to shed light on the inter-regional relationships that residents of Harappa engaged in during the urban transformation of their settlement and society by identifying the geologic sources of the rock and mineral resources that they acquired. Provenience determinations, generated through both broad and fine-scale analyses of the site's stone and metal artifact assemblage and periodized with reference to the detailed chronological sequence presented in the previous section, are used to inform three lines of inquiry. The first two concern identifying the Harappans' inter-regional interaction/acquisition networks, defining their extent and tracking them through time. The third involves elucidating synchronic variations in those networks at the local or site level.

### First line of inquiry: Harappan interaction/acquisition networks and their extent

There has been a great deal of speculation (which I review in upcoming chapters) regarding where it was that Indus Civilization peoples, their Early Harappan predecessors and Late Harappan successors obtained rock and mineral resources; who they came into contact with as a consequence; and the overall scope of those inter-regional trade activities. These issues constitute this study's first line of inquiry, which asks: *With whom in the Greater Indus region or beyond were the residents of Harappa interacting (directly or indirectly) when they acquired rock and mineral resources? What was the extent of those inter-regional relationships/resource acquisition networks during different periods in time?*

Much of this study rests on one assumption – that the acquisition of rock and mineral resources by residents of Harappa would have entailed either direct or indirect *interaction* with peoples dwelling in the regions from which such resources came. Stated

another way, it is considered to be highly unlikely that Harappans (or whoever was supplying them or supplying their suppliers) traveled into a region, obtained a resource and then left without having had any contact whatsoever with local populations. Although this seems almost self-evident, it is an assumption that needs to be declared at the outset. It is recognized that, like the issues of domination and the control of raw materials within source areas, actual face-to-face contacts between different individuals or groups in regions outside of Harappa cannot themselves be positively confirmed using the type of data produced for this study. Nevertheless, **residents of Harappa will be said to have had interacted with the peoples of a particular geographic region when the material (rock or mineral) composing a stone or metal artifact excavated at the site is determined, through one of the methods outlined in Chapter 3, to have most likely been derived from a source in that region.** This does not necessarily mean that site residents met or even had knowledge of peoples living in all source areas – only that they "interacted" with them through the transfer of material goods.

The avenues through which the stone and metal artifacts examined in this study came to Harappa will be called *acquisition networks*. The term "acquisition," as it is used here, is meant only to indicate that someone at the site *gained possession of* (acquired) a raw material or finished item at some point in time prior to it entering the archaeological record there. Acquisition may have occurred as "direct contact trade" between residents of Harappa and the peoples of a region where an artifact originated or as "indirect exchange" involving one or more (perhaps many more) intermediary groups (Lamberg-Karlovsky 1972; see also Renfrew and Bahn 1996: 352 for variations on those forms). The manner in which a stone or metal artifact was moved from Point "A" (source) to Point "Z" (Harappa), the places it passed through along the way (points "B" through "Y") and the number of groups that were involved in the process is not determinable through provenience studies. What can be determined (with varying degrees of confidence and geographic precision) is the location of Point "A." That information enables us to infer *who* (which regional cultural phase) was most likely present at a rock or mineral acquisition network's point of origin.

As this study proceeds, it will be shown that, in some cases, the cultural phase associated with an acquisition network's point of origin is the same one to which residents of Harappa belonged (i.e., Ravi, Kot Dijian, Harappan or Cemetery H depending on the period). In other cases, it is a different Early Harappan phase or a non-Harappan phase. Still in other cases, the source of an artifact is determined to be located in an area where no archaeological remains contemporaneous to those at Harappa have yet been identified. When all such instances are considered for each of Harappa's chronological phases individually (as they are in Chapter 13), a series of detailed "pictures" of rock and mineral acquisition patterns emerge (Figures 13.2 through 13.7) that approximate the *extent* of its resident's inter-regional relationships at different periods in time. These synchronic pictures, although "Harappa-centric" (a feature mitigated somewhat by limited provenience data from other sites – Figure 13.8) and not necessarily representative of the full scope of interaction, can be used to examine general suppositions about culture contact and long-distance trade in northwestern South Asia during the late prehistoric period.

For example, it has been argued that Indus Civilization peoples, their predecessors and their successors had cultural connections and/or trade relationships with groups in various regions surrounding the Indus Valley such as (but not limited to) the highlands of Balochistan (Fairservis 1975; Kakar 2002), the Subcontinent's mountainous north (Allchin 1984; Stacul 1985) and parts of Rajasthan (Agrawala and Kumar 1982; Hooja 1994; Misra 1995). The synchronic pictures of rock and mineral acquisition generated in this study indicate that

Harappan connections/relations with peoples in some regions, especially those to the north of the Indus Valley, were stronger than is generally supposed. They also suggest that ties to other regions, notably Rajasthan, *may* have been less significant than previously thought.

Another issue to be examined concerns the extent to which rock and mineral resource acquisition networks were *internal* or *external* (designations discussed on pp. 40-42; see also Kenoyer 1991a: 358-361) to Harappan society. Some scholars feel that external trade with western Asia, in particular Mesopotamia, was a significant factor in the development of urban lifeways in the Greater Indus region (Asthana 1976; Possehl 1990; Ratnagar 2004). Others have argued that nearly all of the raw materials found at Harappan sites could have been acquired through internal networks and that the role of external trade in that regard has been overstated (Chakrabarti 1990; Lahiri 1990; Shaffer 1982). Still others argue that while the Indus Civilization was a product of indigenous developments, "once the urban phenomenon was established, external trade was a critical factor to the internal controls that maintained the Indus structure" (Kenoyer 1991a: 361). When the pictures of the full extent of rock and mineral acquisition are examined in Chapter 13, it is evident that, during all periods, some materials came from sources beyond the Greater Indus region. However, nearly all such sources were in areas directly adjacent to that region. So while it can be said that external trade for rock and mineral resources was a constant feature at Harappa, there is no clear evidence, at present, indicating that acquisition networks extended to western Asia.

Finally, one of the most interesting and potentially important outcomes of this first line of inquiry involves what it reveals about regions for which the prehistoric period is, at present, poorly understood. As previously mentioned (p. 25), it will sometimes be the case that the point of origin (source) for a particular rock or mineral acquisition network is determined to be located in an area, such as the Hazara District of the NWFP, where no archaeological remains (Harappan or otherwise) contemporaneous to those at Harappa have yet been identified. That, of course, does not mean that the area surrounding the source was uninhabited. There are many parts of northwestern South Asia that have not been surveyed in detail or even at all. Moreover, sites in some regions may have been entirely lost to cultural and, especially in the tectonically active mountains of the northern Subcontinent, environmental processes. The only evidence that people were present in (or at least periodically visited) such areas during the Harappan Period might end up coming from studies such as this one. Knowledge of the extent of Harappan rock and mineral acquisition networks could allow us to "fill in the gaps" so to speak.

An issue that comes up repeatedly throughout this book concerns the problem of Shortughaï – the previously discussed (p. 10) Harappan outpost in northern Afghanistan. At present, there are no other known Indus Civilization sites located between Shortughaï and Musa Khel, which is the next nearest Harappan settlement located 550 km to its southeast on the northern edge of the Punjab Plain. Traveling to and from northern Afghanistan would have necessitated that Harappans either go through or around the Hindu Kush. Until now, there have been few indications as to which of the many possible routes (Chakrabarti 1990: 117-131; Channing 1885; Dale 1994: 46-55; Thomas and Knox 1994: 91-94; Markham 1879) they might have taken. However, if provenience determinations made for raw materials such as steatite (Chapter 7), vesuvianite-grossular (Chapter 9) and alabaster (Chapter 10) from Harappa and other Indus sites are indicative of the regions from which Harappans were accessing resources along the way, then some routes may have passed through what today is Pakistan's North-West Frontier Province (Appendix 13.1).

### Second line of inquiry: Diachronic changes in interaction/acquisition patterns

Questions in the second line of inquiry ask: *How did the patterns of inter-regional interaction/acquisition exhibited by residents of Harappa change over time?* The diachronic perspective necessary to address them is generated when the multiple synchronic pictures of Harappan rock and mineral acquisition produced for the first line of inquiry are regarded simultaneously. In Chapter 2, I present an overview of the culture phases that existed across northwestern South Asia from the early fourth through mid-second millennium BC. That, along with Harappa's own cultural sequence, provides the backdrop against which any evident diachronic changes (or lack thereof) in its resident's acquisition patterns are examined and, in Chapter 13, interpreted. Two ancillary queries related to changes in rock and mineral use and acquisition over time at Harappa are also outlined in this section.

Over the period of time (early third through mid-second millennium BC) that urban lifeways first emerged, existed and then waned in northwestern South Asia, the culture phase that residents of Harappa belonged to variously expanded, contracted, coalesced with other phases, split apart and shifted across the landscape (see Figure 2.6 on p. 41 for a series of maps depicting these changes). Several questions relating to those societal and geographic transformations are taken up in the second, diachronic line of inquiry. To begin with: Did the Harappan's rock and mineral acquisition networks expand from the pre-urban Ravi Phase (Period 1), which currently appears to have been confined to the western Punjab, to the incipient urban Kot Diji Phase (Period 2), which extended approximately 1000 km from Sindh in the south to the Himalayan foothills in the north? Similarly, as the various regional pre/incipient urban Early Harappan culture phases coalesced into the Indus Civilization starting at around 2600 BC, did stone and metal artifacts from new sources reflecting the extra-regional scope of that urbanized society's internal interaction networks begin to appear in Harappa's assemblage? When the cultural horizons of site resident contracted (apparently) from regions to the north of the Indus Valley around that same time did their rock and mineral acquisition networks follow suit? Were acquisition patterns uniform throughout the urban phase (Period 3) at Harappa or did changes in their direction and extent occur during that long (≈ 700 years) period? Did a shift in the Harappan's acquisition networks accompany the dissolution of the Indus Civilization (ca. 1900 BC) and the eastward demographic movement of the Late Harappan Cemetery H culture phase?

Affirmative answers to some of the above questions will serve to support current views of inter-regional interaction and cultural development during South Asia's first period of urbanization. That is, some of the provenience data from Harappa provide new details that corroborate the sequence of extra-regional developments that scholars have previously defined through studies of settlement patterns, material culture affinities and other types of long-distance trade (the sequence and the studies are reviewed in Chapter 2). For example, steatite and lead artifacts attributable to sources in the southern Balochistan region first appear at Harappa in levels dating to the site's urban phase (Period 3). This finding corresponds well with the established extra-regional sequence. The Early Harappan phases that residents of Harappa belonged to during periods 1 and 2 did not extend into southern Balochistan. It was not until Period 3 at Harappa that Indus Civilization peoples were present in that region at sites like Balakot and Bakkar Buthi and, presumably, had first-hand access to raw materials occurring there. The appearance at Harappa in Period 3 of steatite and lead from southern Balochistan sources is no doubt indicative of the extensive internal trade networks that had emerged by the Integration Era of the Indus Tradition[5].

Negative answers to some of the questions posed

in this diachronic line of inquiry are also highly informative. For instance, the Early Harappan phase that Harappa's residents belonged to during Period 2 – the Kot Diji Phase, extended north across the Salt Range to the foothills of the Himalayas. Resources attributable to sources in those highland areas dominate the site's rock and mineral assemblage from that time. During the subsequent urban phase (Period 3 at Harappa), no Indus Civilization settlements (save for distant Shortughaï) have been found beyond the Salt Range, which creates the impression that Harappan interaction with previously occupied regions in the north diminished or ceased entirely. However, the diachronic picture of rock and mineral acquisition generated for this study suggests otherwise as the networks bringing stone and metal resources to Harappa from northern sources evidently continued unabated throughout the urban phase. Among the many implications of these findings (discussed in Chapter 13) is the possibility that there are undiscovered Harappan settlements in the north and/or that a "Late" Kot Diji Phase continued in that region concurrent with the Indus Civilization.

***Two ancillary queries concerning diachronic changes***

Two ancillary queries – one related to diachronic changes in the overall composition of Harappa's rock and mineral assemblage and the other to changes in the acquisition and use of heavy or *bulk* stone goods – are examined at appropriate points in this book.

*- Diachronic changes in assemblage composition*

Firstly, I evaluate the assertion by Dilip Chakrabarti (1998: 51) that, despite a marked intensification in craft specialization between the Early Harappan and Harappan periods in the Greater Indus region, there was "hardly any major change" in the types of raw materials used during those times. Is this characterization correct? At the outset of this project I thought perhaps it was not. It seemed reasonable to think that, because of the substantially larger geographic area encompassed by the Indus Civilization (as compared to the various Early Harappan societies) and its clear links to regions outside of South Asia such as Oman (Cleuziou 1992), consumers during the Harappan Period may well have had a wider variety of raw materials types available to them. Moreover, the development of new craft technologies during that period might have permitted some previously unusable types of raw materials to be exploited. A diachronic examination of the composition of Harappa's rock and mineral assemblage, which was fully inventoried and periodized for this study (Chapter 4), offered a good opportunity to test Chakrabarti's assertion. As it turns out, the basic suite of raw materials that was used at the site does appear to have been largely the same during both the Early Harappan and Harappan phases. Most (but not all) discrepancies between the phases can be attributed to the lower probability of recovering less abundant rock and mineral varieties in earlier, less extensively excavated levels.

*- Diachronic changes in the acquisition and use of bulk stone goods*

I have termed the largest and heaviest objects at Harappa *bulk* stone goods. By diachronically querying the record of where such goods were acquired and when certain varieties of them were used, it has been possible to examine emerging transportation capabilities and observe the appearance of what could be interpreted as a new expression of social status.

The vast majority (≈ 95%) of stone and metal artifacts recovered at Harappa are small in size and light in weight. Most weigh between a few milligrams up to a few hundred grams. Even though nearly all such artifacts probably first came to the site as part of larger, heavier pieces of raw material (unworked stones, roughouts or ingots) it is unlikely that the original pieces themselves weighed more than a few

5) see definitions and descriptions on pp. 37 & 45-47.

kilograms. There were doubtlessly some exceptions. Several very large chert flakes and cores (see Figure 6.33 and 6.34) have been recovered at Harappa that suggest heavy (perhaps up to 30 kg) chert nodules may have sometimes been transported to the site in whole or minimally reduced form. Of course, it is impossible to say with certainty that this was the case until at least one example is recovered. For this study, artifacts designated as bulk stone goods (≈ 5% of the assemblage) were those that weighed from one to 150 kilograms or are smaller fragments that were unquestionably once part of objects of that weight. With very few exceptions, such artifacts are either grindingstones (querns and mullers) or large-sized limestone objects such as ringstones.

The very largest bulk stone artifacts at Harappa do not even closely approach the weights of some of the monumental stones that were quarried and moved by other ancient societies (see Heizer 1966 for examples). Nevertheless, getting them to the site, which is hundreds of kilometers from any source, would have required, as compared to smaller varieties of stone, a significant expenditure of energy and specialized transportation capabilities. Of course, moving individual, heavy loads made up of many of smaller stones – say 20 kg bags of agate nodules – would have also required those things. However, because they were dispersed, it is impossible to know (without written records) exactly how heavy were there single shipments of small-sized raw materials actually. In contrast, the sandstone from which a 20 kg quern was fashioned clearly could have weighed no less than 20 kg when it was conveyed to Harappa. This is the unique feature of bulk stones. Although it is hard to quantify, some degree of expense/value can be confidently associated with even the most mundane of such goods because of their weight and the difficulty inherent in moving them.

By focusing on factors of weight/size and distance/direction to sources, it was possible to diachronically query the records of the two main types of bulk stone goods at Harappa. In Chapter 5, I argue that the trend away from the acquisition of querns and mullers from relatively nearby occurrences of poor quality stone toward more distant sources of higher quality material is due, in part, to the advent of new technologies (i.e., wheeled transport) that facilitated the long-distance transportation of heavy bulk goods. In Chapter 11, I tentatively interpret the finding that non-utilitarian bulk-sized limestone objects (some weighing over 100 kg from sources over 800 km away) were used only during latter part of urban phase to reflect a new development in the way that certain Harappans expressed their social status through the consumption and display of stone.

#### Third line of inquiry: Site-wise synchronic variations

Earlier (pp. 7-8) I discussed Kenoyer's thesis (2000) that those groups who ruled Indus Civilization cities acquired and maintained their power to do so, in part, by controlling essential raw materials as well as the manufacture and distribution of status-defining items. Kenoyer argued (ibid.: 89-90) that extensive inter-regional interaction networks in combination with the wide distribution and multiple occurrences of essential resources across northwestern South Asia "stimulated economic competition and more complex economic and political interaction between the early village communities" of the ancient Indus Valley. Economic power and political authority, rather than being concentrated in a single individual, institution or community, instead came to be distributed among multiple groups of competing elites. By the urban phase this was reflected in the segregated layout of Indus Civilization cities. The multiple walled and gated areas at settlements like Harappa and Mohenjo-daro are thought to have been "centers of power" where competing elites not only dwelled but also controlled access to valuable resources and the production/distribution of the wealth and status-defining items made from them (Kenoyer 1997a:

69). It is these issues – competition and the control of essential rock and mineral resources, which are the focus of this study's third line of inquiry: *Did synchronic variations in patterns of rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?*

The expectations are fairly straightforward. If the major mounds at Harappa (recall Figure 1.4) were inhabited by separate communities which were ruled by elites actively competing with one another through the control of essential resources and goods, then synchronic variations in the material variety and/or geologic provenience composition of the site's rock and mineral artifact assemblage *might* be observable. For example, if it is determined that a specific material variety was used only (or mainly) on a particular mound, then this could be construed as evidence that the inhabitants/rulers of that mound closely controlled access to that material. Similarly, if it is found that communities on different mounds were utilizing the same variety of rock or mineral but from different geologic sources, then this could be viewed as evidence for competition between the elites who presumably controlled the raw materials coming into those areas.

Ultimately, phase-by-phase synchronic assessments of Harappa's rock and mineral assemblage revealed both striking similarities and some notable differences among its mounded areas. Overall, it appears that, during all periods, Harappans living and working in different parts of the site had access to and were acquiring raw materials and/or finished goods derived from the same geologic sources. The two biggest exceptions are for vesuvianite-grossular and "Ernestite," which appear to have been almost exclusively used by Harappans dwelling on mounds E and ET.

## CHAPTER CONCLUSION: AN OUTLINE OF THIS BOOK

In this introductory chapter I have presented the principal research objective, the general background to the Indus Civilization; a discussion of theoretical orientation, a review of Harappa's cultural/chronological sequence and an outline of the three lines of inquiry pursued in this study. In Chapter 2, the site of Harappa is placed into its geographic, geologic and ancient temporal-cultural contexts within the Greater Indus region. In Chapter 3, the various research strategies and methods that have been employed in this research are discussed. In Chapter 4, the 56,350 rock and mineral artifacts that have been recovered from Harappa to date are categorized, periodized and quantified. Then, over the next eight chapters, approximately 3000 of those artifacts representing eight main material varieties are subjected to geologic provenience analysis using one (or more) of the methods described in Chapter 3. I begin with a complete analysis of Harappa's grindingstone assemblage (Chapter 5) and then move on to geologic provenience studies of judiciously selected samples from the assemblages of chert (Chapter 6), steatite (Chapter 7), agate (Chapter 8), vesuvianite-grossular garnet (Chapter 9), alabaster (Chapter 10), limestone (Chapter 11) and various metals (Chapter 12). In the end, specific provenience determinations (a source or source area in defined geographic space) were made for 2170 artifacts from Harappa and 119 artifacts from other sites. These data are summarized in Chapter 13, brought to bear on the three lines of inquiry outlined in this chapter, and the implications of the answer to those inquiries are discussed. Brief concluding remarks including thoughts for future studies are presented in Chapter 14.

# CHAPTER 2

# HARAPPA IN CONTEXT

## CHAPTER INTRODUCTION: THE GREATER INDUS REGION

The Indus Civilization, at its greatest extent during the latter half of the third millennium BC (Figure 2.1), is variously estimated to have covered an area of northwestern South Asia ranging from 680,000 (Kenoyer 1991a: 352) to 1,000,000 square kilometers (Jansen 2002: 105). Many Indus settlements are located in geographic regions well beyond the river valley that is its namesake. This prompted Rafique Mughal to propose (1970) the term *Greater Indus Valley* as a way to refer to the broader region that the civilization encompassed. The purpose of this chapter is to situate the focal point of this study – the site of Harappa, into the geographic, geologic and ancient temporal-cultural contexts of the Greater Indus* region (for brevity and consistency I hereafter drop **Valley* from the term).

## GEOGRAPHIC CONTEXT

Harappa is located at N 30° 37' 31", E 72° 51' 52" in District Sahiwal, Punjab Province, Pakistan. From that geographic vantage point in the center of the Punjab Plain near the Ravi River, the site was well placed in terms of access to resource zones both within and immediately surrounding the plain. It is also well situated in terms of other Indus settlements and large urban centers where rock and mineral resources from more distant areas could probably be indirectly obtained. In this section, I provide a brief and general overview of the major geographic features and regions of the Greater Indus region (Figure 2.1) and the principal routes through which residents of Harappa may have interacted with Indus peoples or other cultures living across this broad area. Much greater detail on pertinent features and regions are provided in upcoming sections and chapters.

The Kirana Hills – a series of rocky outcrops 120 km north-northwest of Harappa, are the first and only features in the general vicinity of the site that rise above the flat expanse of the Punjab Plain. On the plain's western margin, 220 km from Harappa, the north-to-south running Sulaiman Mountains begin and from there numerous passes lead up into the highlands of northern Balochistan and from there to Afghanistan and the Helmand Basin. Moving northward, the next closest major features are the Gomal Plain, which is essentially a trans-Indus River extension of the upper Indus Basin alluvial plains and the Salt Range. From there low passes lead north into the Bannu Basin and Potwar Plateau. The most direct routes to the distant Indus Civilization outpost of Shortughaï, located in far northern Afghanistan, would have passed through these regions. Continuing clockwise, Harappans would have needed only to follow the rivers of the Punjab northeast as they passed through Jammu, Kashmir and into the western Himalaya in order to access the rich resources of those regions. Lying east of Harappa are the Indus settlements of the eastern Punjab and Haryana plains including the large urban center of Rakhigarhi, which might have provided indirect access to the resources of the northern Aravalli Mountains as well as the central Himalaya. To the south-southwest of Harappa, the Indus city of Ganweriwala and other related sites along the now dry Ghaggar-Hakra River system are points where interaction with ancient desert nomads




**Figure 2.1** Map showing approximate extent (dashed line) of the Indus Civilization, its five main cities and the major regions and features of the Greater Indus region.

in the Cholistan region (Mughal 1994b) who might have had access to the resources of western Rajasthan. The Ghaggar-Hakra and the parallel-running Indus River would have been the main southward routes from Cholistan and the Punjab toward the Sindh region and Mohenjo-daro, the largest Indus city. Raw materials from the Rohri Hills, the Kirthar Range, Sindh Kohistan and southern Balochistan may have passed northward to Harappa along these same riverine routes. From northern Sindh, it would have been possible to follow the Bolan River through the Kachi Plain and into the highlands of

central Balochistan. Finally, from southern Sindh, a Harappan trader may have the traveled westward to Indus settlements and outposts in the Makran region or continued south to Gujarat and the Indus city of Dholavira.

## GEOLOGIC CONTEXT

In relation to the geology of the Greater Indus region (Figure 2.2), Harappa simply could not be more optimally located for provenience studies of its rock and mineral artifacts. The region is dominated by an immense (approximately 1200 km long by 600 km wide at its greatest extents) bowl-like depression, called the *Indus Valley Basin* (or simply Indus Basin), which is filled with alluvial sediments. Harappa is located upon the upper portion of this basin ("upper Indus Basin") and, with the exception alluvial clays and sands, there are no rock or mineral resources whatsoever to be had within a minimum distance of 120 km of the site. This situation is a boon rather than a hindrance to provenience studies. There is no need to attempt to determine what stone or metal resources found at the site are local and what are not because none of them are. All lithic artifacts at Harappa had to have come from one of the many, highly varied (another big positive in terms of provenience studies) geologic formations within or surrounding the alluvial plain (itself a geologic formation) of the Indus Basin. Here, I collectively refer to those non-alluvial formations as the "highlands," although some are merely very low hills or outcrops that barely rise above the plains. In this section, the general geology of the Greater Indus region is discussed in terms of its alluvial plains and highlands.

In this section and at various points throughout this book, I refer to geologic formations using terms that designate their relative chronological age (geologic Eras, Periods and Epochs). In certain instances, I also provide absolute dates. For those times that I do not, a geologic timescale (Appendix 2.1) has been provided for reference.

### The Alluvial Plains

The physical character of the Indus Basin alluvial plain is a product of the many rivers and streams that flow through it, as well as various tectonic and aeolian processes (Beg 1993; Flam 1993b). Throughout the Pleistocene and Holocene epochs, its major watercourses have migrated to new locations, been captured by other rivers or have disappeared entirely (Oldham 1887; Roonwal 1968; Thussu 1999). The rivers on the maps used throughout this book are based on what their courses *may* have looked like around 2000 BC (Wilhelmy 1969). It is still not clear as to whether or not the now dry Ghaggar-Hakra-Nara system ever flowed to the sea (Flam 1993b; Possehl 1998a) so its possible course through the Sindh region is marked as a dashed line on those maps. The actions of the Indus and other rivers flowing through the basin have resulted in the formation of a variety of alluvial features including floodplains, terraces, meander scars, oxbow lakes and tablelands (see Belcher and Belcher 2000, Pendall and Amundson 1990 and Schuldenrein 2002 for detailed geoarchaeological accounts of these features). The high areas between major rivers are known as *doabs* or *bar uplands* and rise as much as 15 meters above the flood plains (Bender 1995c: 300). Although the climate of the Indus Basin plains is generally arid, its fertile alluvial soils combined with winter rains and summer monsoons create the potential for abundant harvests (Weber 2003: 176).

Harappa lies in the center of the broadest portion of the upper Indus Basin alluvial plain, an area known as the *Punjab*. The name "Punjab" literally means the "land of the five rivers" – *panj* (five) *ab* (waters). Traditionally, this refers to the region watered by the Jhelum, Chenab, Ravi, Beas and Sutlej rivers. Physically (and, during various periods, politically) the Punjab has been defined as inclusive of most or

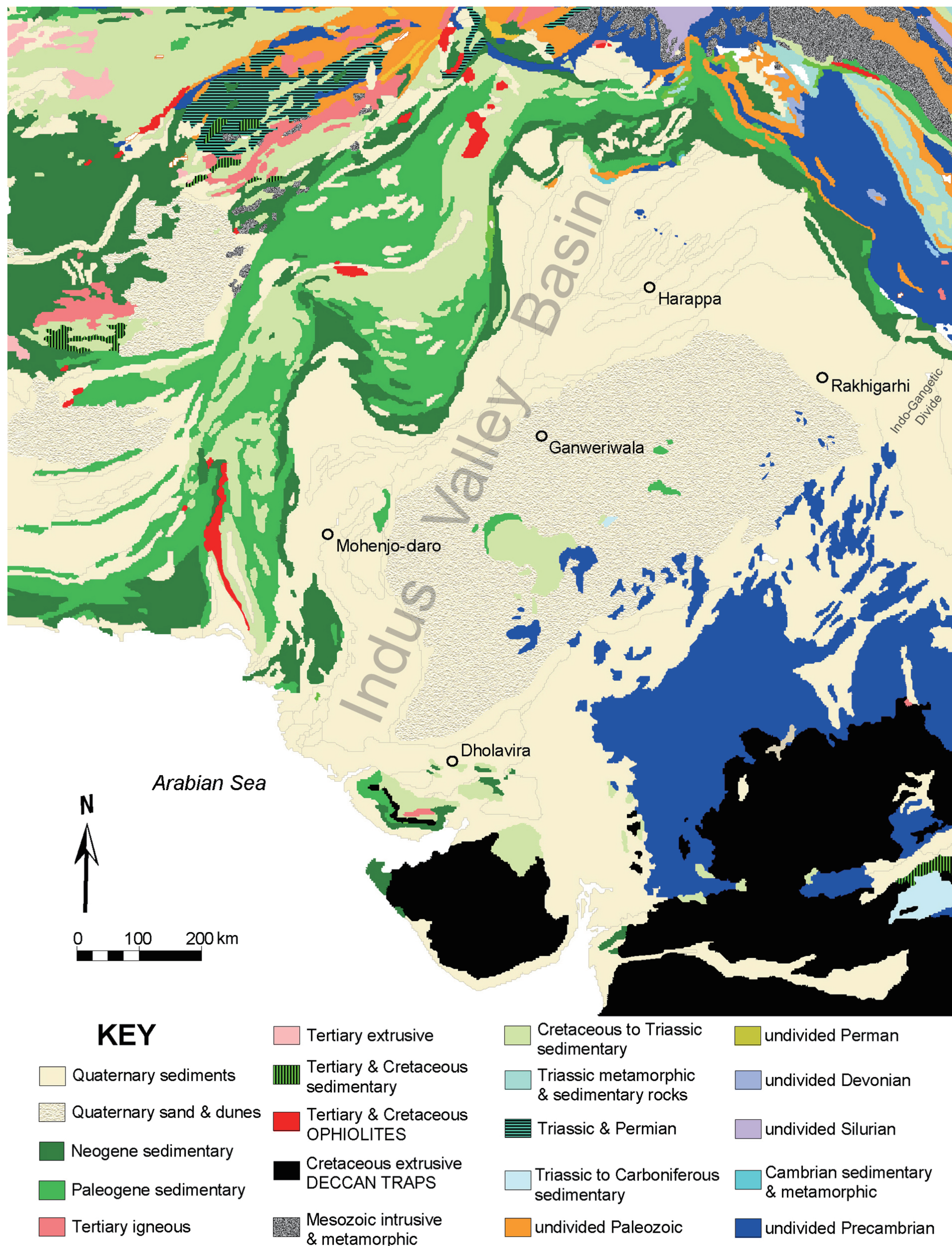



**Figure 2.2** General geologic map of the Greater Indus region (adapted and simplified from Wandrey and Law 1998 - USGS Open-File Report 97-470C).

all of the alluvial lands comprising the upper portion of the Indus Basin (Figure 2.2) – from the Sulaiman Range in the west to the Indo-Gangetic divide in the east and from the Salt Range and Himalayas in the north to Sindh and the deserts of Rajasthan in the south (Government of Great Britain - India Office 1908: 245-46). The designation "Punjab Plain" as used in this study refers to this larger region.

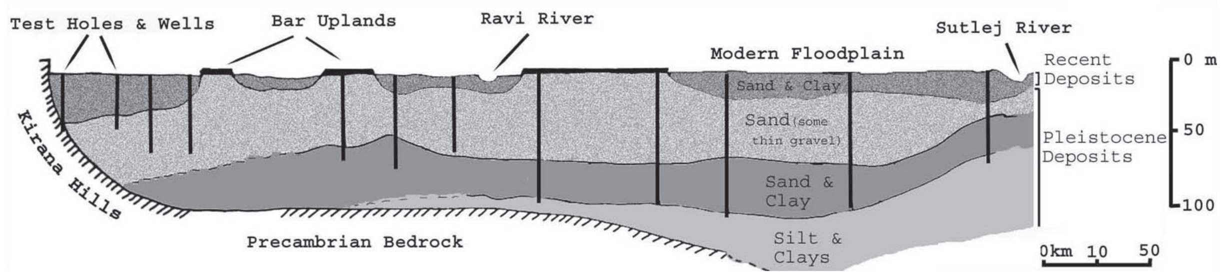



**Figure 2.3** Cross section of the Punjab Plain looking northeast from Harappa (after Kazmi 1995c: Fig. 3.14 C).

The physical landscape of the plain clearly influenced settlement patterns in the Punjab and elsewhere. Proto-historic sites discovered in the Punjab tend to be located on or near the edges of the doabs (Schuldenrein *et al.* 2004: 779). Such settings would presumably have provided early agriculturalists access to the fertile and well-watered lands of the flood plains while generally keeping their villages above the normal annual flood levels. These locations would have also been situated along important riverine transportation and communication routes.

In terms of the present study, it is of utmost importance to note that the alluvium of the Punjab Plain has been accumulating since at least the early Pleistocene and it is, therefore, extremely deep (Kazmi and Jan 1997: 267). Cross-sections based on tube well logs (Figure 2.3) indicate that, in some places, depths of 100 m or more (in places much more) exist before Precambrian bedrock is reached. With the exception of sporadic an deeply buried thin beds of gravel (ibid.), pedogenic carbonate nodules or kankar (Amundson and Pendall 1991: 18) and subsurface formations of gypsite in the deserts of Rajasthan and Cholistan (Joshi 2000; Ahmad 1969: 92), the alluvial strata of the upper Indus Basin is composed solely of sand, silt, clay and loess for no less than 120 km surrounding Harappa. Every rock and mineral object recovered at the site, from the tiniest pebble to the largest quern, had to have been purposefully transported there by some human agent(s). Therefore, all stone or metal artifacts can potentially provide information about the interaction networks that linked Harappa to various rock and mineral sources in the outcrops, hills and mountains (highlands) within and surrounding the Indus Basin.

## The Highlands

The highly varied nature of rock and mineral assemblage at Harappa (Chapter 4) is a reflection, at least in part, of the diverse geologic sources that residents of the site had access to in the highlands of the Greater Indus region (Figure 2.2). The Indian subcontinent's collision with the Asian Plate beginning approximately 55 million years ago (Powell 1979: 16) is the ultimate source of this diversity. Enormous beds of sedimentary detrital rock (sandstone and shale), carbonates (limestone and dolomite) and sulfide evaporates (gypsum and anhydrite) developed in the shallow Tethys Sea that existed prior to and during the convergence of the two continental plates (Bender 1995a: 11–13). As the Indian Plate subducted beneath Asia, these beds were folded, raised and exposed in massive sequences along the northern and western margins of the Indus Basin (Farah *et al.* 1984: 161–163). Another product of this subduction was the development of volcanic island arcs and their associated rocks (basalt, rhyolite, andesite, etc.), which eventually were emplaced between the sutured continental margins (Shams 1995a: 131–133). Similarly, large fragments of oceanic crust (*ophiolites* – composed of ultramafic rocks and containing radiolarian cherts) were obducted onto the continental crust (Asrarullah and Abbas 1979). Pressure and stress from the collision altered existing

geologic formations in myriad ways and brought to the surface highly metamorphosed rock from as deep as the earth's mantle (Shams 1995a). East of the Indus Basin, one of the oldest portions of the earth's crust, the Indian basement complex, rose in the form of the Aravalli Mountains. Rich deposits of base metals and metamorphic minerals can be found across the length of that range (Wadia 1975: 94–95). Finally, a wide variety of agate, carnelian and other microcrystalline silicate geodes eroded from the basalts of the Deccan Traps that extend into the Gujarat region southeast of the Indus Valley (Merh 1995: 166-167).

Several scholars have argued that ancient Indus Tradition peoples likely acquired certain varieties of rocks and minerals from the beds of rivers flowing from the mountain ranges surrounding of the Indus Basin, thus making it unnecessary for them to have traveled to in situ geologic formation containing of those materials (Inizan and Lechevallier 1990: 51–52; Kenoyer 1998: 35; Khan *et al*. 1988: 102). And for certain materials this is indeed, to some extent, true. However, it would be a mistake to think of riverbeds or the alluvial fans at the base of mountain ranges as cornucopias containing all of the types of stone found in the formations that they drain. River-borne sediments undergo rapid fining through abrasion, chipping, splitting, cracking and chemical weathering as they are moved downstream (Werrity 1992). Tough rocks such as granite, limestone and sandstone have slower attrition rates than softer materials that are easily fractured (ibid.: 343). A resident of Harappa seeking a sandstone grindingstone would have needed only to travel to one of the massive alluvial fans at the base of the Sulaiman Range to get a suitable cobble rather than into the mountains themselves. However, to obtain a material like chert, which easily becomes chipped and fractured as it is carried downstream, or steatite, which quickly disintegrates, it was probably necessary to travel to the actual source or, at least, very close to it. Although further studies are needed, preliminary observations (Appendix 2.2) of the movement of red radiolarian jasper down the Tochi River from sources in North Waziristan indicate that this material becomes highly fractured and rare at the point the river nears prehistoric sites on the Bannu Basin plain, such as Lewan (Allchin and Allchin 1993). Similar examinations were made of drainages in central Balochistan, confirming Inizan and Lechevallier's observations (1990: 52) that good quality chert in Bolan River near Mehrgarh is actually quite scarce. It is certainly possible that slope gradient and river discharge may have changed since prehistoric times, thus altering and/or obscuring the composition of drainages that once contained good quality material. However, it is much more likely that then, as now, someone needed to travel directly to source deposits in order to obtain most of the varieties of rocks and minerals found at Harappa.

## TEMPORAL-CULTURAL CONTEXTS

Jim Shaffer noted (1982: 192) that "with the exception of turquoise and lapis lazuli" all raw materials used to make the objects found at Indus Civilization sites occur "*within* the distribution area of the Harappan culture in the Greater Indus Valley" [italics added]. This is true, more or less, for most types of stone or metal used at Harappa during the urban phase and is demonstrated on a material-by-material basis in the next chapter. However, many of those artifacts were deposited when people dwelling at the site were not members of an urbanized society as extensive as the Indus (Harappan) Civilization. Both prior to and following the urban phase (Period 3) at Harappa, there were numerous varieties of raw material for which all potential sources would be considered "external" (*a la* Gupta 1984; Kenoyer 1991a: 358-61) to the larger regional society/culture that the site's residents belonged to during those periods of time. In order to evaluate diachronic change in the extent of the inter-regional interaction

networks that Harappans participated in, it is necessary to 1) provide a temporal framework (one broader than the site's chronology, which was outlined in Chapter 1) with which to examine those networks in an extra-regional context and 2) to situate Harappa (its residents and rock and mineral assemblage) in relation to its regional and extra-regional cultural contexts.

### Traditions, eras and phases

In this book, I will be following the chronological framework for ancient South Asia that Jim Shaffer (1992) adapted from a system originally developed by Willey and Phillips (1958) for New World archaeology. Underlying this framework are the concepts of *traditions*, *eras* and *phases*.

A "tradition" is a "persistent configuration of technologies and cultural systems within a context of temporal and geographic continuity" (Shaffer 1992: 442). Although an often highly diverse range of human adaptations existing over long spans of time may be encompassed within a tradition, they are all broadly related and collectively distinct from those of groups belonging to other traditions. Along with the *Indus (Valley) Tradition*, which may be thought of as the milieu of cultural/technological adaptations in the Greater Indus region within which urbanized civilization eventually emerged and existed, Shaffer defined (ibid.) the *Balochistan* and *Helmand* traditions to encompass concurrent but distinct cultural developments in those two regions west of the Indus Valley. Using Shaffer's framework, Kenoyer (1991a, *in press* b) has further defined several other traditions contemporaneous to that of the Greater Indus region: the Ganga-Vindhya Tradition (Ganges Basin and Vindhya region), the Malwa-Rajasthan Tradition (Aravalli Range region and Malwa Plateau) and the Bactria-Margiana Tradition (southern Central Asia).

Traditions are sub-divided into *eras* and *phases* (Shaffer 1992). Figure 2.4 is table showing those for the Indus Tradition. "Eras" are descriptive units in which cultural "phases" (below) are grouped based on their general attributes (such as basic subsistence economy) and differing degrees of interaction/integration. They are non-evolutionary and do not have set temporal or geographic boundaries. Several may exist concurrently in a tradition (e.g., Indus Tradition Foraging era groups co-existed with Regionalization era communities up until the Integration era) or even be absent entirely (some traditions, for instance, do not experience Integration and Localization eras). Eras are made up of "phases," which are defined on the basis of a set of distinctive material culture traits (frequently this is a diagnostic assemblage of ceramics) present in a specific place and time. They are of short duration as compared to traditions and eras but may encompass a geographic area ranging from that of a single site to an entire culture tradition. Site specific chronologies, such as that for Harappa (Figure 2.4 third column), intersect with certain phases and may cut across multiple eras and even traditions.

### Ancient settlements of the upper Indus Basin

Our understanding of the ancient "cultural landscapes" (Sauer 1925) in which Indus Civilization cities developed and existed has grown tremendously since the original excavations of Harappa and Mohenjo-daro. Possehl provides a comprehensive account of the many expeditions and surveys that have been conducted in the Indus Valley and the regions surrounding it in his 1999 book *Indus Age: The Beginnings*. In this section, I focus primarily on the discovery of ancient sites in the upper Indus Basin region (Figure 2.5). These settlements constituted Harappa's cultural hinterland and provided the links across the vast alluvial plain of the Punjab to rock and mineral source areas in the highlands.

At that time it was originally excavated, Harappa was one of only three Indus Civilization settlements

**Figure 2.4** Eras and phases of the Indus Tradition
(modified from Belcher 1998; Kenoyer 1991a and in press b; Shaffer 1992)

| **Eras**<br>"Text" (Shaffer 1992: 442) | **Phases** | **Harappa**<br>see Figure 1.6 for dates |
|---|---|---|
| **Foraging Era**<br>ca. 10,000 to 2000 BC | Mesolithic and Microlithic | |
| **Early Food Producing Era**<br>ca. 7000 to 5000 BC<br><br>"Economy based on food production and the absence of ceramics" | **Mehrgarh Phase** | |
| **Regionalization Era**<br>ca. 5000 to 2600 BC<br><br>"Distinct artifacts styles, essentially, ceramics, which cluster in time and space and interaction networks which link dispersed groups" | **Early Harappan Phases**<br>Hakra Phase<br>SKT/Tochi-Gomal Phases<br>Balakot Phase<br>Ravi Phase<br>Kot Diji Phase<br>Sothi-Siswal Phase<br>Amri Phase | Ravi Phase – Period 1<br><br>Kot Diji Phase – Period 2 |
| **Integration Era**<br>ca. 2600 to 1900 BC<br><br>"Pronounced homogeneity in material culture distributed over a large area reflecting an intense level of interaction" | **Harappan Phase**<br>Indus Civilization<br><br>Late-Kot Diji<br>Kulli<br>Sorath | Harappa Phase – Period 3A<br>Harappa Phase – Period 3B<br>Harappa Phase – Period 3C |
| **Localization Era**<br>ca. 1900 to 1300 BC<br><br>"Comparable to regionalization except that there is a more generalized similarity in artifact styles, indicating continued, but altered, presence of interaction networks" | **Late Harappan Phases**<br>Punjab (Cemetery H)<br>Jhukar<br>Rangpur | Harappa/Late Harappa<br>Transitional Phase – Period 4<br>Cemetery H Phase – Period 5 |

known to exist in the entire upper Indus Basin region, the others being a small mound called Chak Purbane Syal 27 km away and another called Kotla Nihang Khan 350 km away on the eastern edge of the Punjab Plain (Vats 1940: Chapter XIX). Eventually, however, many more prehistoric sites (not all of them of them Indus Civilization settlements) were discovered through reconnaissance and survey. The bulk of these were found along the drainage of the now dry Ghaggar-Hakra River (Stein 1942; Mughal 1997). Many were also identified on the plains of the eastern Punjab and Haryana (Bhan and Shaffer 1978; Joshi and Bala 1993). In Pakistan, clusters of sites were found along the margins of the upper Indus Basin on the Gomal Plain (Dani 1971), Bannu Basin (Khan *et al*. 1988) and Potwar Plateau (Halim 1972). Yet during that time few sites, with the notable exception of Jalilpur (Mughal 1974b) and Vainiwal (Mughal 1972b), were found in the western Punjab in the general vicinity of Harappa. For decades the site seemed to "exist in a near vacuum" (Fentress 1982: 254). The apparent absence of Indus Civilization settlements between Harappa and the Salt Range led Possehl (1984) to hypothesize that the region at that

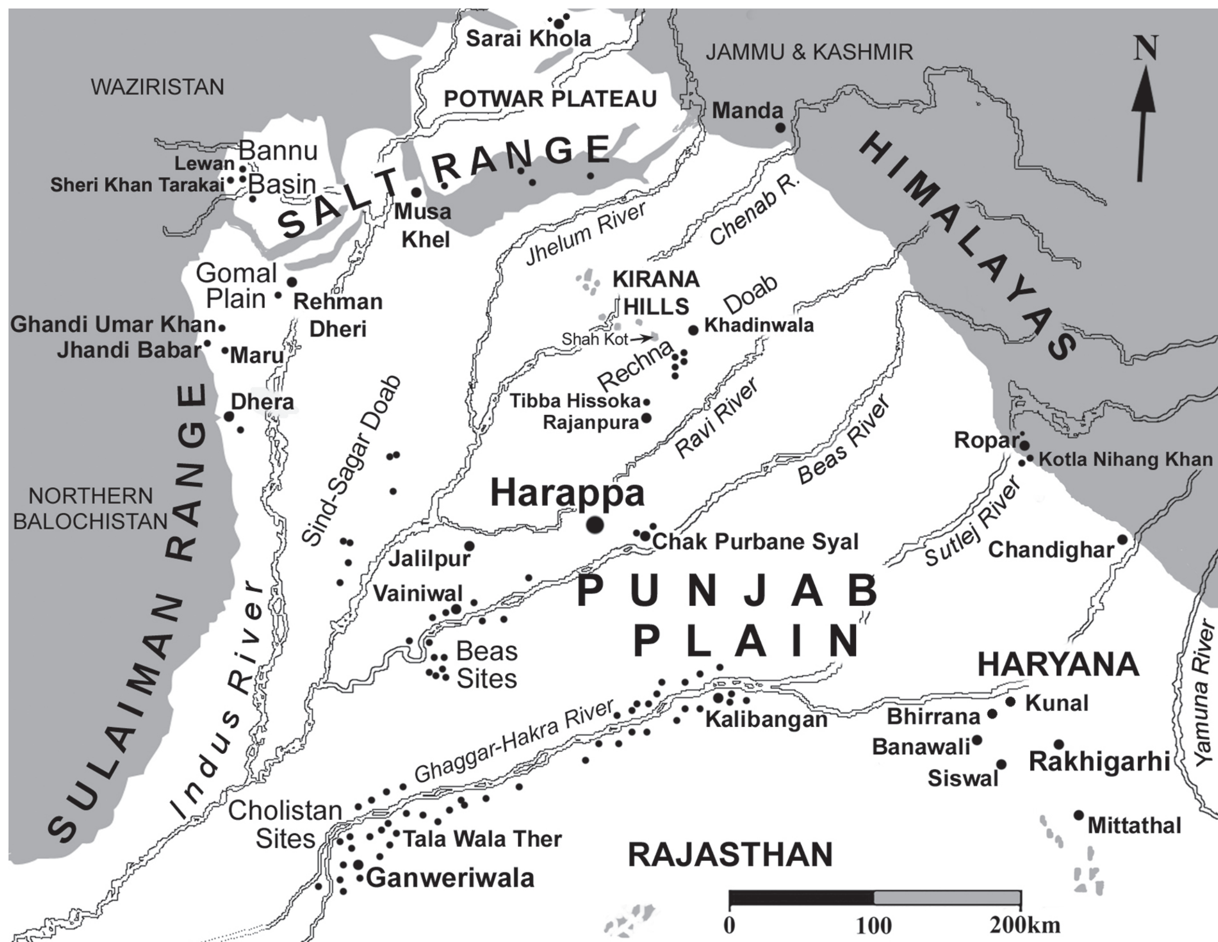



**Figure 2.5** Select Regionalization and Integration Era sites of the Upper Indus Basin

time may have largely been the domain of ancient pastoralists who had little impact archaeologically upon the landscape. Even as late as the 1990s it seemed to some scholars unlikely that a significant number of sites would ever be discovered on the plains of the western Punjab region (Chakrabarti 1995: 36).

Fortunately, the preliminary results of recent surveys directed by the Department of Archaeology and Museums, Government of Pakistan (Mughal *et al*. 1996) and others have begun to fill gaps in our knowledge regarding the prehistoric cultural landscape of the western Punjab Plain. Around 40 sites, ranging in age from the early to mid-fourth to the mid-second millennium BC, have been located in the area between the Sutlej and Indus rivers. Eighteen were discovered south along the old bed of the Beas River (Wright *et al* 2002; Schuldenrein *et al*. 2004). Nine were found in the doab (called the Rechna doab or Sandal Bar) between the Ravi and Chenab rivers (Dar 1983, Qasim 2002; Dogar *in press*). Seven were located around 125 km west of Harappa in the southern Sind-Sagar (Indus-Jhelum) doab (Mughal *et al*. 1996: 111-12). Several others have recently been identified in the Salt Range (Dar 2002) and, although not plains settlements, have helped to bridge what once was a significant cultural void between prehistoric settlements in the Punjab and the distant group of Early Harappan sites clustered around Sarai Khola on the northern Potwar Plateau (Halim 1972). These discoveries in a region once thought to be largely devoid of settlements are a good indication that there may be “many more sites in the Punjab waiting to be documented” (Mughal 1990a: 184).

The northern part of the Punjab Plain (from the Salt Range to the Chenab River) is one area that still awaits survey. At the end of the 19th century the archaeological remains of this region were described

in the *Gazetteer of the Shahpur District*:

> In the Bár tract between the valleys of the Chenáb and Jhelum rivers there are some 270 mounds of earth mixed with loose bricks and fragments of pottery which mark the sites of former towns and villages. It is unlikely that those sites were inhabited at any one time. More probably they were built upon when the rivers flowed in one or other of the old channels still existing in the Bár (Wilson 1897: 30-31).

The above description is, in a way, reminiscent of the Cholistan desert region on the southern fringe of the upper Indus Basin. There, hundreds of prehistoric sites belonging to various phases are located along the numerous dry river beds marking where the Ghaggar-Hakra flowed at different points in time as it migrated across its former floodplain (Mughal 1997). If the density of prehistoric sites in the western Punjab appears low when compared to that of a well-surveyed arid region like Cholistan, then it could be due, at least in part, to factors other than pronounced differences in settlement intensity. Agriculture is one of the greatest destroyers of archaeological sites the world over and the extensive irrigation system built during the British period turned the semi-arid bar uplands into highly productive farmland. Across the Punjab the destruction of mounds for fields and/or fertilizer is quite common (*personal observation*). It was also noted in the Shahpur Gazetteer that saltpetre was "manufactured in considerable quantities from the numerous mounds in the cis-Jhelum tract which mark the sites of former villages" (Wilson 1897: 18). The shifting rivers of the Punjab have no doubt obliterated the remains of ancient settlements just as they have done to populated towns and villages in fairly recent times (Punjab Government 1898: 6-7). Other sites, especially low mounds and surface scatters of the kind that are easily observable in arid Cholistan, have likely been obscured by the deposition of 4000-plus years worth of alluvial sediments. Still others probably lay beneath the modern villages, towns and cities of this heavily populated region. Although all of this does not prove that the plains surrounding Harappa were as densely settled during the late prehistoric period settled as Cholistan evidently was, it does provide good reason to suspect they were probably not as sparsely populated as they might now appear to have been.

Our knowledge of the ancient settlement patterns of the Punjab is fragmentary and, because of the nature of the region, is likely to remain so. Nonetheless, the results of recent surveys have begun to provide a somewhat clearer picture of the region's cultural landscape during the late prehistoric period. Urbanization is a regional-scale phenomenon and cities cannot develop in isolation. The identification of contemporaneous settlements on the doabs surrounding Harappa demonstrates that it was far from being isolated.

### The transforming cultural landscapes of the Indus Tradition

The cultural landscape of the Greater Indus region underwent several dramatic transformations during the fourth through second millennia BC (the period covered by Harappa's prehistoric/protohistoric chronological sequence). In this section, I review the various phases of the Regionalization, Integration and Localization eras of the Indus Tradition (Figure 2.6) along with pertinent concurrent phases in other traditions. The purpose of this review is two-fold. The first is to supply basic information (approximate age, geographic extent and important cultural associations) for cultural phases that are referred to repeatedly throughout this book. The other is to provide cultural contexts/associations for the various rock and mineral artifacts that are the subjects of this study as well as for their potential geologic sources. Provenience studies reveal that, during certain phases, some varieties of stone used by residents of

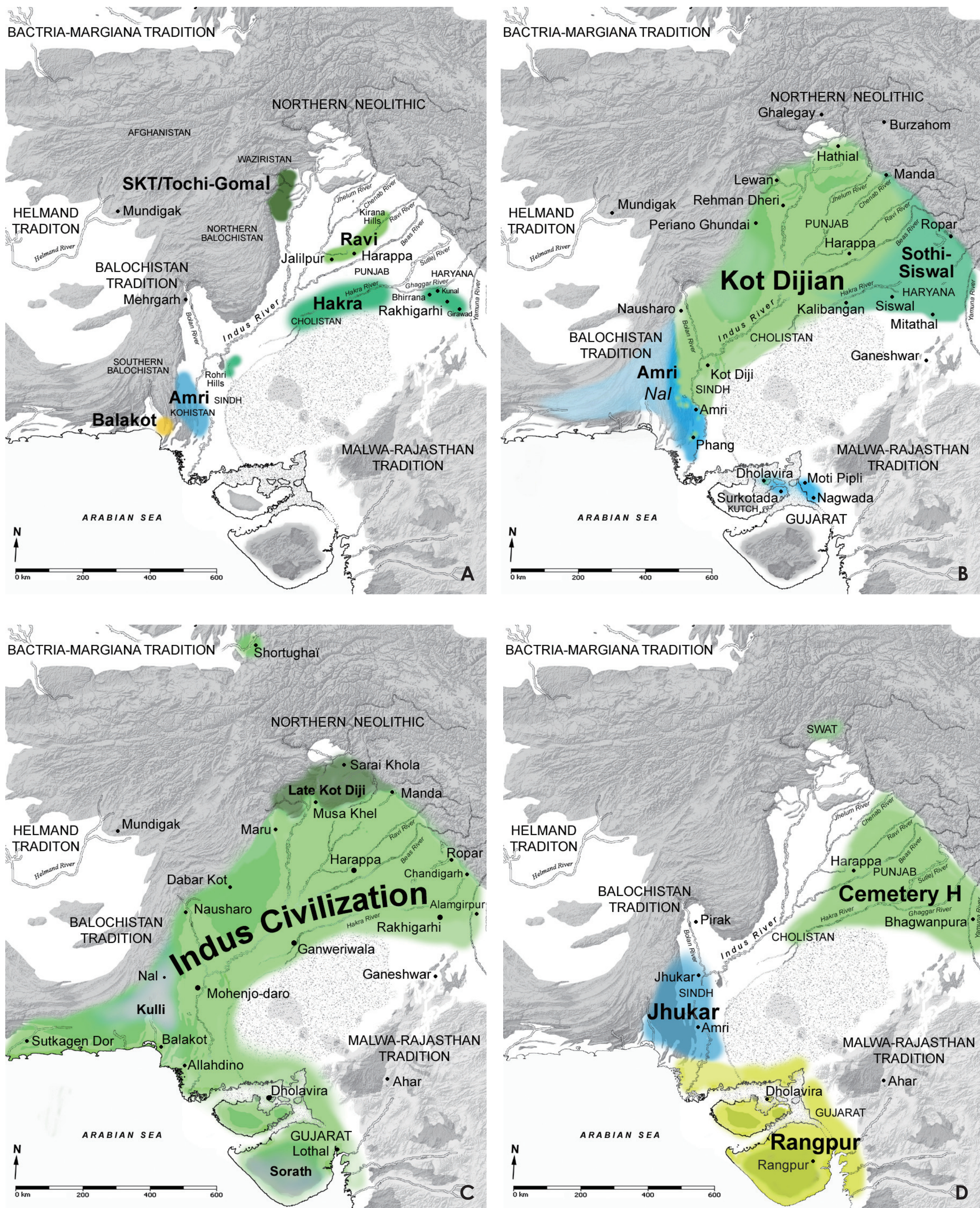



**Figure 2.6** Indus Tradition cultures of the Regionalization, Integration and Localization Eras [**A**] Regionalization Era – Ravi Phase (Harappa) (ca. mid 4th to mid 3rd millennium BC). [**B**] Late Regionalization - Kot Diji Phase (Harappa) (2800 to 2600 BC). [**C**] Integration Era – Harappa Phase Indus Civilization (2600 to 1900 BC). [**D**] Localization Era – Late Harappa (Harappa).

Harappa came from sources within the geographic area encompassed by settlements of the cultural phase to which they belonged. In such instances, the acquisition networks for those particular materials are considered *internal*. For other phases, certain stone resources were derived from locations outside of the area where sites of that phase are currently known to lie. Those acquisition networks are considered

*external* and some form of interaction with the cultural group dwelling in the source region (if one has been identified) is implied.

***Regionalization era (Early Harappan Period)***

Period 1 (ca. 3300 to 2800 BC) and Period 2 (2800 to 2600 BC) at Harappa are defined by Indus Tradition Regionalization Era phases. Below, I discuss these along with the other Indus Tradition phases that existed during those periods. First, however, I must further discuss a term that is now widely used describe these phases and the time period.

The central thesis of Prof. Rafique Mughal's 1970 dissertation was that the early third millennium BC cultural phases of the Greater Indus region, which were at that time represented by excavated assemblages at Amri, Kot Diji, Harappa and Kalibangan and by surface collections from several other sites, shared with one another important attributes that, in a few centuries, would become distinctive features of the Indus (Harappan) Civilization. Synthesizing all of the data then available, Mughal argued that these phases, although regionally distinct, were direct historical antecedents to that civilization and collectively characterized them as being essentially *Early Harappan* in nature. Walter Fairservis (1975: 221) came to a similar conclusion around this time and proposed the same term. Based on newer excavation, survey and radiocarbon data, Mughal later (1990a) revised the definition to encompass phases in certain regions where they were previously not known and developments extending as far back as the mid-fourth millennium BC. "Early Harappan" is now widely (though not universally) used to denote those broadly related Indus Tradition Regionalization Era phases that existed during the millennium or so prior to the emergence of the Indus Civilization. It is used in that sense here.

*- ca. 3300 to 2800 BC*

The founders and early residents of Harappa belonged to the *Ravi* culture (Kenoyer and Meadow 2000), which was one of the several regionally distinct Indus Tradition societies now recognized to have existed in the Greater Indus region during fourth to early third millennium BC (Figure 2.6 A; see also Figure 2.5 for site and region names). Archaeological remains representing this phase are, at present, only known at sites along the mid to lower reaches of the Ravi River drainage. Besides Harappa, two small Ravi settlements – Rajanpur and nearby Tibba Hissoka, lie approximately 80 km to the northeast of the site in the Ravi-Chenab (Rechna) doab (Dogar *in press*), near what appears to be one of the Ravi River's former watercourses. In addition, Kenoyer and Meadow feel (2000: 58-59) that the earliest levels (Period I) at Jalilpur (Mughal 1974), which lies approximately 70 km to the west-southwest of Harappa, probably represent a Ravi culture occupation at that site. The southernmost outcrop of the Kirana Hills at Shah Kot (noted with an arrow on Figure 2.5), which lies around 40 km north of Tibba Hissoka (the northernmost Ravi site), is the closest source of stone to any of the currently known Ravi Phase settlements.

Jalilpur Period I had earlier been designated a *Hakra* culture occupation (Mughal 1990b) and was seen to have close affinities to the nearly 100 sites of that phase identified in Cholistan – a region around 200 km to its south-southwest (Mughal 1997). The differing interpretations of early Jalilpur levels are not surprising or necessarily irreconcilable. Ravi Phase Harappans exhibited many similarities with their Hakra contemporaries living along the then active Ghaggar-Hakra river system, especially with regard to their lithic (to be discussed) and ceramic assemblages (Kenoyer and Meadow 2000). This, in all likelihood, indicates that there was a great deal of interaction between peoples of the two regions. In addition to permanent agricultural villages (some up to 26 ha in area), numerous short-term camps with microlithic tool technologies have been discovered in Cholistan, which suggest that pastoral activities were a significant

component of Hakra culture lifeways (ibid.). Such activities were likely one of the principle avenues through which long-distance interaction with peoples in distant regions took place. Some of this interaction was directed southward, as evidenced by the cluster of Hakra sites identified 300 km southwest of Cholistan near the Rohri Hills of northern Sindh (Mallah 2000, 2008; Shaikh *et al.* 2002). Ceramics described as "Hakra wares" have also been reported to the east of Cholistan in the earliest levels at Bhirrana (Rao 2006), Kunal (Khatri and Acharya 1995) Rakhigarhi (Nath 2001) and Girawad (Shinde *et al.* 2008) in Haryana. As studies of those wares continue, it is possible that they may be found to actually represent a regionally distinct phase with important parallels to the Hakra culture, much like the Ravi Phase at Harappa.

On the western margin of the upper Indus Basin, settlements belonging to the *Sheri Khan Tarakai* (abbreviated SKT on figures 3.4 and 3.6 A) phase and the subsequent *Tochi-Gomal* phase are found in an area extending from the Gomal Plain into the Bannu Basin (Khan *et al.* 2000, 2002b). Farid Khan and the other members Bannu Archaeological Project believe that the strongest cultural affinities, at least for the earlier phase, lie west of the region with sites in Afghanistan and southern Central Asia (Khan *et al.* 1991b: 170). However, important material culture analogies between the fourth and early third millennium BC peoples of the Bannu-Gomal region and those represented by Ravi Phase levels at Harappa in the Punjab have been noted by excavators working in both areas (Kenoyer and Meadow 2000: 63; Khan *et al.* 2002a: 87). This is a significant association in terms of this study because unlike Hakra Phase sites, most of which are clustered in a region almost entirely devoid of rock and mineral resources, the Sheri Khan Tarakai and Tochi-Gomal phase cultures were situated directly adjacent to the resource-rich highlands of the western Salt Range, Waziristan and northern Balochistan as well as along the natural routes through those regions into Afghanistan and, ultimately, Iran and Central Asia.

Far to the south, two other regionally distinct Indus Tradition cultures also emerged at this time. Several dozen sites of the *Amri* Phase are found across an area that extends from the highlands of Sindh Kohistan and the Kirthar Piedmont to a short distance out onto the plains of the lower Indus Basin (Casal 1964; Flam 1981). Slightly farther to the southwest in the Las Bela region of southern Balochistan, Period A levels (end of fourth millennium to around 2700 BC – Franke-Vogt 1997) at the site of Balakot constitute all that is presently known of the *Balakot* Phase (Shaffer 1992). George Dales' studies of the "Balakotian" ceramic assemblage (1974: 11) indicated that varying degrees of interaction existed with both Nal culture (a Balochistan Tradition phase) groups to the north and Amrian peoples to the northeast. Although ceramic parallels that would indicate a similar degree of interaction with the Regionalization Era cultures of the upper Indus Basin are not evident at Balakot, marine shell artifacts (usually bangle fragments) are found at Hakra, Ravi and Sheri Khan Tarakai phase sites (Kenoyer and Meadow 2000: 64; Khan *et al.* 1991a: 59; Mughal 1997: 68). Although this does not specifically link those cultures with the Amri and Balakot phases, it does demonstrate that long-distance trade networks extending from the upper Indus Basin to the Arabian Sea coast were in place by this time.

*- 2800 to 2600 BC*

The cultural landscape of the Greater Indus region at around 2800 BC remained a mosaic of distinctive regional societies. Those belonging to the Indus Tradition at this time were the *Kot Diji*, *Amri* and *Sothi-Siswal* phases (Figure 2.6 B). In parts of the Greater Indus region where survey coverage and site preservation are good (Cholistan and southwestern Sindh), it has become evident that three or four-tiered settlement hierarchies already existed during

this period (Mughal 1990a: 192). Excavations at Harappa (Meadow and Kenoyer 2001), Kalibangan (Bala 2003; Joshi 2003), Dholavira (Bisht 1991), Rehman Dheri (Durrani 1988; Durrani *et al.* 1995b), Kunal (Khatri and Acharya 1995) and other sites with Early Harappan occupations have brought to light features such as massive platforms and fortification walls, the first cubical stone weights and stamp seals and post-firing graffiti on pottery and other types of evidence relating to the development of the Indus writing system (note that not every Early Harappan site, including most listed above, possesses all of these attributes). Many scholars are increasingly of the opinion an "early," "proto" or "incipient" form of urbanism had emerged in parts of the Greater Indus region by this period (Allchin and Allchin 1997: 205; Durrani *et al.* 1995b; Flam 1981: 183; Meadow and Kenoyer 2001: 23; Mughal 1990a). Although not everyone is convinced that such designations are justified (for views to the contrary see Chakrabarti 1998: 46-47 and Possehl 1986: 95-96; 1990), it is at least clear that many of the technologies and innovations that are among Kenoyer's (1991a) necessary preconditions for the development of urbanized society (Figure 1.2) were, in some areas, already in place.

The most extensive cultural phase of this period was that of the Kot Diji culture, so named after the small site in northern Sindh near the Rohri Hills where it was first defined (Khan 1965). Period 2 levels at Harappa are entirely "Kot Dijian" in character. The scale of cultural integration represented by sites of this phase is enormous (Mughal 1992a). A distance of almost exactly 1,000 km exists between the northernmost known Kot Dijian settlement (*Hathial* – Khan 1983) and the southernmost one (*Phang* – Harvey and Flam 1993). Within that area, sites of this phase are found throughout Sindh (Flam 1981; Mallah 2000), Cholistan (Mughal 1997), northern Balochistan (Fairservis 1975; Mughal 1974a), the Gomal Plain (Durrani 1984), Bannu Basin (Allchin *et al.* 1986), the western Punjab Plain (Mughal *et al.* 1996); the Salt Range (Dar 2002) and to the northern edge of the Potwar Plateau (Halim 1972). Importantly for this study, numerous rock and mineral sources were now situated within the geographic area encompassed by settlements of the cultural phase to which residents of Harappa belonged. In addition, there is strong evidence that Kot Dijians were interacting with peoples of other traditions and phases living in potential source regions external to that area, such as the "Northern Neolithic" cultures inhabiting the mountain valleys of the northern Subcontinent at this time (Possehl 1999: 542-553; Stacul 1992, 1994). Ceramics of "indubitable" Kot Dijian character were discovered in the Neolithic levels of Burzahom in the Kashmir Valley along with agate and steatite beads that are almost certainly trade items from the Indus region (there are no local analogues for such beads but they are common at Harappa and other Indus sites) (Pande 2000: 392; Saar 1992). Such ceramics have also been recovered in third millennium BC levels at Ghalegay and several other sites in the mountain valley of Swat, NWFP (Stacul 1987). At the opposite end of the Greater Indus region, Kot Dijian sites are found in close proximity (in some cases less than 10 km) to those of the Amri Phase (Flam 1981). Kot Dijian ceramics at many Amrian sites provide evidence for both the contemporaneity of the two cultural phases and a high degree of interaction between them (Possehl 2002a: 117).

The Early Harappans that lived on the plains of the eastern Punjab and Haryana at this time have been defined as belonging to the *Sothi-Siswal* phase (Possehl 1999: 685). If one compares Sothi-Siswal and Kot Dijian ceramic assemblages across the regions where they found, a gradual "continuum of variation" in forms and stylistic traits is evident between them rather than a sharp boundary (Possehl 2002a: 123). This likely indicates that "strong lines of communication" existed between the peoples of these

two phases (ibid.: 124). Sothi-Siswal Phase Early Harappans living at sites adjacent to the Himalayan foothills like Manda (Joshi and Bala 1982), Ropar (Sharma 1982) and Chandigarh (Shaffer 1981: 87) would have had excellent access to the rock and mineral resources of that region. Those at Mitathal (Bhan 1969) and other settlements in southern Haryana were best positioned to acquire copper and other resources found in the northern Aravalli Range. Doing so would have brought them into contact with Rajasthan-Mawal Tradition peoples (Ganeshwar-Jodhpura Phase), like those now known to have been dwelling at Ganeshwar since about 3000 BC (Agrawala and Kumar 1982; Rizvi 2007).

The Amri phase continued in southwestern Sindh at this time. Ceramic parallels suggest that Amrians had close ties with peoples of the *Nal* Phase of southern Balochistan. Shaffer (1992) defines the Nal culture as a separate phase in the Balochistan Tradition while Possehl (following Fairservis 1975) treats the Amri and Nal phases as two aspects of a single Early Harappan cultural phenomenon (*Amri-Nal*), which was "bound together by the seasonal movement of agropastoralists and other itinerants" between the southern Balochistan highlands and the plains of lower Sindh (Possehl 2002a: 115-118). Although I continue to follow Shaffer's framework here, I have graded the blue shaded areas on Figure 2.6 B to reflect the approximate sphere of interaction between peoples of the two phases (light blue for the western area were Nal sites are predominantly located and a darker blue for the eastern region where Amrian sites tend to be found). As I noted earlier, there was also a Kot Dijian presence in southwestern Sindh at this time. Rock and mineral resources from locations within the interaction sphere of the Amri and Nal peoples could have entered the extensive Kot Dijian interaction networks at this point and then been transported through them to consumers at Harappa.

Finally, there is evidence suggesting that Early Harappan peoples may have begun to settle in northern Gujarat at this time and/or were interacting with indigenous non-Early Harappan peoples of that region to a significant degree (Possehl 1999: 603-612). In Kutch, ceramics with both Amrian and Kot Dijian cultural affinities are present in the earliest occupational levels (Stage I and Stage II) at Dholavira; a site which was a settlement that would subsequently become one of the five major Indus cities (Bisht unpublished 1993 report cited in Ajithprasad 2002). Early Harappan ceramics (both Amrian and Kot Dijian-like) have also been found in eastern Kutch at Surkotada (Possehl 1997b) and on the North Gujarat Plain at Nagwada (Hegde *et al.* 1988, 1990) and Moti Pipli (Majumdar and Sonawane 1997). Prominent among the many rock and mineral resources of this region that Early Harappans may have wished to acquire are ornament-quality microcrystalline silicates and amazonite.

***Integration era – 2600 to 1900 BC***

By the mid-third millennium BC the regional cultures of the Early Harappan Period had largely coalesced into the urbanized society known as the Indus Civilization. In Shaffer's framework (1992) this is the *Harappan Phase* of the Indus Tradition. It represents an approximately seven century-long era during which peoples living in distant and ecologically diverse regions of northwestern South Asia (Figure 2.6 C, see also figures 3.1 & 3.5) were culturally, economically, and, perhaps to varying degrees, politically *integrated*. A system of well-developed, intensive and sustained inter-regional interaction networks made this possible. Archaeologically, the result was a large number of sites with remarkably similar material culture remains spread across an immense geographic area. Marking the approximate western extent of the main or "core area" (Mughal 1990a) of Harappan Phase settlements are Dabar Kot in northern Balochistan (Stein 1929), Nausharo at the foot of the Bolan Pass (Jarrige 2000) and Sutkagen-Dor on the Markan coast near the modern boarder

with Iran (Dales 1962). Lothal in Gujarat (Rao 1979a, 1985) is one of the southernmost sites of this phase and the earliest levels at Alamgirpur in Uttar Pradesh (IAR 1958-59) indicate that Indus Civilization peoples were living as far eastward as the Gangetic Basin. Harappan Phase occupations are found along the northern margin of the upper Indus Basin at Chandigarh (Shaffer 1981: 87), Ropar (Sharma 1982), Manda (Joshi and Bala 1982), Musa Khel (Dani 1971) and at several sites in the Gomal Valley such as Maru (Khan *et al*. 2000). Importantly for this study, geologic sources for nearly all of the rock and mineral varieties used by residents of Harappa during this time (Period 3 at the site) occurred within (internal to) or very close to the Indus Civilization's core area.

Without the benefit of written records it is difficult to determine the degree to which the Indus Civilization was politically integrated. By 2600 BC, large urban centers had emerged at Ganweriwala in Cholistan (Mughal 1997), Rakhigarhi in Haryana (Nath 1998), Dholavira in northern Gujarat (Bisht 1991), Mohenjo-daro in Sindh (Marshall 1931b) and, of course, Harappa in the Punjab. Kenoyer (1997a) feels that these cities were regional loci of political and economic power and probably represent independent polities not unlike "city-states." Ratnagar (1991: 169), on the other hand, argues that many factors, including the widespread use of standardized "infrastructural elements" (bricks, chert and metal tools, carts, etc.), points to "political unification under one state." Over the course of the Indus Civilization's 700 year existence it is quite likely that the scale of political integration fluctuated (Kenoyer 1994b). Perhaps both scenarios were true at different times. Presently, however, it is not possible to state if such fluctuations actually occurred, much less when. In this study, I am only able to say whether or not a specific rock or mineral acquisition network appears to have been external or internal to the Harappan *cultural* "core area."

A pronounced degree of cultural integration during the Harappan Phase of the Indus Tradition is evident from the widespread use of very specific material items and symbols that reflect a common and deeply-held ideology (Miller 1985). However, older notions that sites of this phase exhibit a "uniformity" (Piggott 1950: 140), "monotonous regularity" (ibid.: 136) and "astonishing sameness" (Wheeler 1950: 29) over the enormous area where they occur have given way to research showing that important regional variations did exist, most notably in terms of ceramics styles and subsistence regimes (Possehl 1992b). Based on these variations as well as settlement patterns and geography, Possehl (1992b, 2002a) has defined different Harappan "domains" within the Indus Civilization – e.g. Sindhi Harappan, Bahawalpur Harappan, East Punjab Harappan, etc. Even though this is a tempting way to conceptualize and organize cultural variability over this huge area, I am going to resist using Possehl's "domains" here because I feel that doing so would suggest the existence of political, social and perhaps even ethnic divisions that have not yet been satisfactorily demonstrated. Although it is plain that, culturally, the Indus Civilization was an internally differentiated society rather than a monolithic one, for the purposes of this study the groups of people making it up are collectively considered "Harappan."

Precisely where Harappan culture ended and non-Harappan began is not always clear cut, however. "Harappan" status has been given to some regional groups for which that designation, although not baseless, is arguable. For instance, during the latter half of the third millennium BC southern Balochistan appears to have been occupied by both Indus peoples and the locally distinct *Kulli* culture (Franke-Vogt *et al*. 2000). Kulli peoples did use some ceramics and iconographic elements that were Harappan in character. Possehl considers them to have been a highland variant of the Indus Civilization (Possehl 1986: 61) – i.e. "Kulli Harappan" (Possehl 1992b). Similarly, a large portion of the Saurashtra

Peninsula of Gujarat was occupied by peoples that Possehl calls "Sorath Harappans" (Possehl 1992a). They too possessed many elements of Harappan material culture but they also lacked some important ones such as stamp seals. It is quite plain that there were strong connections between the Indus Valley and areas like the southern Balochistan highlands and Saurashtra at this time. Whether or not the peoples in the latter two regions represented highly distinctive variants of the Indus Civilization or were local groups who had absorbed certain cultural elements from their Harappan neighbors remains to be determined, however. Therefore, on the Figure 2.6 C, the green-shaded area marking the extent of the Indus Civilization is faded out in the Kulli and Sorath culture areas so as to reflect where the "veneer" (a word I borrow from Dr. Richard Meadow) of Harappan culture is thinner.

Immediately north of the Indus Civilization, in the Bannu Basin, Gomal Plain and Potwar Plateau areas, there is evidence that the Kot Dijian phase continued concurrently with the Harappan Phase. Contemporaneity between the two phases is indicated by both radiocarbon dates and finds of items with clear Harappan affinities at otherwise wholly Kot Dijian-type sites in those areas (Allchin 1984; Dani 1971; Thomas and Allchin 1986; Xu 1990). Interaction with "Late" Kot Dijian Phase peoples would have afforded Harappans indirect access to the rich rock and mineral resources of the northern Pakistan highlands.

There is abundant evidence demonstrating that Harappan interaction networks extended well outside of the Greater Indus region during the Integration Era (Tosi 1993). The site of Shortughaï in northern Afghanistan (discussed on pp. 10 & 26) provides some of the clearest such evidence. The fact that Harappans journeyed to (and presumably from) that distant settlement opens the possibility that rock and mineral resources occurring along the many routes through northern Pakistan and Afghanistan were accessible at this time. Toward the west, Harappan seals and beads have been found at a number of sites across the Iranian Plateau (Dales 1976; Heskel 1984; Lawler 2007; Tosi 1979). Seals and other items at Altyn Depe in Turkmenistan indicate that some interaction between Harappans and local Bactria-Margiana Tradition peoples took place within southern Central Asia (Hiebert 1995; Masson 1981). Beginning around the end of the third millennium BC, Bactria-Margiana Tradition (BMAC phase) peoples were themselves making inroads into northwestern South Asia (Hiebert and Lamberg-Karlovsky 1992; Jarrige 1991a; Meadow 2002; Parpola 2005).

At the southern end of the Harappan world, there is ample evidence on both sides of the Arabian Sea for the existence of seaborne trade between the Indus Civilization and the ancient cultures of northeast Arabia (Chakrabarti 1998; Cleuziou 1992; Cleuziou and Tosi 1994; Edens 1993; Possehl 1997a; Rao 1979b; Ray 2003). Farther to the west, textual records suggest that Harappan merchants and craftsmen were living in Mesopotamia at this time (Parpola *et al.* 1977; Vidale 2004) and that numerous goods were being imported into that region from "Meluhha" – the Sumerian name for the Indus region (Asthana 1976; Chakrabarti 1990; Kenoyer 2008; Possehl 1996; Ratnagar 2004). What was traded to "Meluhha" in return is unclear as items of obvious foreign origin (Mesopotamian or otherwise) are extremely rare at Indus Civilization sites (Possehl 2002c). It might have been perishable goods that are now archaeologically "invisible" (Crawford 1973) or raw materials that were subsequently transformed by Harappan consumers. Ratnagar (2004: 199) has argued that silver was a Mesopotamian import while Kenoyer and Miller (1999) feel that the copper resources of Oman were the impetus for trade with that region.

***Localization era – 1900 BC to <1300 BC***

Around 1900 BC, the Indus Civilization began to undergo a significant transformation as many

of its cities, along with the interaction networks that supported urbanized society in northwestern South Asia, were either abandoned or dramatically reduced in scale. Within a century or so three localized phases (Figure 2.6 D) had emerged in the previously integrated region – *Rangpur* in Gujarat, Jhukar in Sindh and Cemetery H in the upper Indus Basin and western Gangetic Basin (Mughal 1992b). Although the peoples of these phases retained many cultural features that justify the use of the term "Late Harappan" to describe them, they had abandoned others (the Indus script, weights, stamp seals) that were hallmarks of the Indus Civilization. The particulars of the general "deurbanization" seen during the Late Harappan period and the reasons behind it are not yet fully understood but research in recent decades has made it clear that the outcome of the transformation was not the same in all parts of the Greater Indus region (Possehl 1997c; Sonawane 2002). In Sindh and Cholistan there was a precipitous decrease in settlement density while in Gujarat, the eastern Punjab, Haryana and western Gangetic Basin there were many more sites than in the previous phase. Evidence from Cemetery H (Period 5) levels at Harappa indicate that activity and innovation continued in the western Punjab at this time despite the apparent cessation of long-distance interaction networks with Sindh and Gujarat (Kenoyer 2005b). Finds of Cemetery H ceramics in the Swat Valley (Stacul 1985) show that interaction between the Indus plains and the mountainous north continued.

## CHAPTER CONCLUSION

Harappa's geographic position in center of the Punjab Plain was optimal from the standpoint of its being centrally located. Geologically, however, this was a resource-poor area. The site's residents had to import all stone from sources located no less than 120 km away. Access to those sources shifted as the cultural landscape that they were a part of transformed over time. It was within these contexts that the artifacts making up Harappa's rock and mineral assemblage were acquired, used and discarded. In the next chapter, I review the research strategies and methods used to identify the sources of those artifacts.

# CHAPTER 3

# STRATEGIES AND METHODS FOR SOURCING STONE AND METAL ARTIFACTS

## CHAPTER INTRODUCTION: STRATEGIES AND METHODS

In order to address the lines of inquiry outlined in Chapter 1, it is necessary to know precisely what kinds of rocks and minerals are present in Harappa's artifact assemblage and, for select varieties of those materials, to ascertain which geologic sources they were most likely acquired from. The purpose of this chapter is to review the various research strategies and methods that were employed to accomplish those two tasks.

Reeves and Brooks (1978) outlined a series of steps (Figure 3.1) for successfully determining the geologic provenience of rock and mineral artifacts, which will serve as a guide for the presentation of this chapter. I begin with a discussion of the importance of utilizing the extensive body of geologic literature relating to South Asia as the primary reference source for locating the natural occurrences of the different rock or mineral types being investigated (Step A). Emphasis is also placed on the benefits of directly working with geologists. The discussion then shifts to the geologic field studies that were necessary for both collecting a representative range of geologic samples from each potential source area (Step B) and for confirming or refuting the existence and/or nature of certain rock and mineral occurrences. I then move on to the issue that ultimately underlies the success or failure of any stone or metal artifact sourcing study – demonstrating that the chemical, isotopic or mineralogical variability *between* the different geologic sources under examination is greater than the variability *within* any individual source (Step C). Many factors contribute to successful source discrimination, such as the choice of sampling strategies (discussed in relation to Step B) and analytical methods (discussed in relation to steps D and E). One issue, which is often not given due attention, relates to the selection of the appropriate geographic scale on which to define stone or metal "sources." After examining the issue of scale and the expectations of provenience resolution

**Figure 3.1** Steps for successful determining the geologic provenience of rock and mineral artifacts (adapted from Reeves and Brooks 1978: 364-365).

**A**. Locating the natural occurrences of the rock or mineral type being investigated.

**B**. Collection of a representative range of samples from each potential source area.

**C**. Demonstrating that the chemical / isotopic / mineralogical variability between different geologic sources is greater than the variability within individual sources.

**D**. Establishing a set of analytical parameters that will allow geologic sources to be distinguished from one another with a high degree of confidence.

**E**. Analysis of rock and mineral artifacts and assignment to a probable geologic in accordance with the criteria established in D.

stemming from it, I proceed on a series of overviews outlining the various methods used to identify and/or characterize archaeological and geologic samples for this study. Also discussed are the analytical methods that were chosen to evaluate the quantitative data obtained from the characterization of selected varieties of stone or metal. Through the application of these methods, parameters were established that allow different geologic sources to be distinguished from one another with a high degree of confidence and artifacts to be assigned to them based on their chemical/isotopic/mineralogical properties (steps D and E).

In the conclusion of this chapter, I stress that statements regarding the geologic provenience of stone or metal artifacts are always *provisional*, regardless of how comprehensive or statistically significant the datasets they are based on may appear to be.

## RESEARCH STRATEGIES

In this section the research strategies that were used to identify potential rock and mineral sources, assemble a collection of geologic samples for analysis and to define suitable scales of provenience resolution are discussed.

### Using primary geologic reference materials to locate potential sources

There have been several major broad-scale studies (Fentress 1976; Lahiri 1992; Ratnagar 2004) of Harappan trade networks that examined multiple varieties of stone and metal to construct models of proto-historic resource access and exchange. However, to identify the rock and mineral sources that were potentially used in the past, those researchers relied heavily upon colonial-era British Government district gazetteers and secondary references such as the source identifications suggested or cited by the writers of early excavation reports. Consequently, their interpretations have serious limitations due to the imprecise, incomplete and occasionally spurious nature of their principal reference materials. I am not suggesting that those types of sources are always wrong or have no value and should be ignored. On the contrary, the reports of late 19th and early 20th century civil servants and archaeologists are sometimes the sole source of information on certain mineral deposits. I myself frequently cite these references throughout this book. However, they alone do not provide a comprehensive picture of South Asian rock and mineral resources and, because their writers usually did not visit geologic occurrences themselves, misidentification of source locations and of the materials themselves could easily have been made. For these reasons, literature of this kind should not be considered the "best sources" (Possehl 1999: 173) to turn to for primary reference material when delineating potential resource areas for rock and mineral artifact provenience studies.

A substantial body of scholarly literature relating to the geology of South Asia exists and was accessed for this study as the *primary reference material* for locating potential sources of the rock and mineral artifacts found at Harappa and other sites. Among the most useful publications were those produced by national government agencies such as the Records, Memoirs and Bulletins put out by the Geological Survey of India and the Geological Survey of Pakistan. Publications by state agencies, such as the Department of Mines and Geology, Government of Rajasthan were also valuable sources data. Dozens of university geology departments in both India and Pakistan regularly publish journals, conference proceedings and books detailing the geologic resources of the state or region that they represent. For decades institutions such as Pakistan's *Centers of Excellence* in Geology (Peshawar) and in Mineralogy (Quetta), the Geological Society of India (Bangalore) and the Wadia Institute of Himalayan



**Figure 3.2** The author conducting fieldwork in Balochistan, Pakistan.
Clockwise from top left - Consulting topo sheets in Muslimbagh, with levies in the Kanrach Valley, sampling steatite at Ugasai Nasir, and collecting bitumen in the Bolan Pass.

Geology (Dehra Dun) have conducted and published groundbreaking geologic research. Public reports produced by organizations like the Gujarat Mineral Development Corporation (GMDC) and the Federally Administered Tribal Areas Development Corporation (FATADC) are also excellent sources of data on mineral resources in those areas. Newer geologic overviews (e.g. Bender and Raza 1995; Kazmi and Jan 1997; Ramakrishnan and Vaidhyanadhan 2008) have been published within the last decade or two that are far more accurate and comprehensive than earlier ones. Lastly, the unique nature of the Subcontinent's geology has attracted researchers from around the world who have collaborated with their South Asian colleagues and published their results in a wide range of international journals.

### Field-checking and sampling potential Harappan rock and mineral sources

After thoroughly searching the geologic literature in order to identify the potential sources of rock and mineral artifacts found at Harappa, the next task was




**Figure 3.3** **[A]** Dr. S.R.H. Baqri (Pakistan Museum of Natural History) in the Rohri Hills, Sindh. **[B]** The sample-laden truck during my fieldwork with Dr. Baqri. **[C]** Dr. Khalid Mahmood (Centre of Excellence in Mineralogy, University of Balochistan) at the Tor Tangi steatite mine, Zhob District, Balochistan. **[D]** Khawar Akbhar (Geological Survey of Pakistan-Karachi) near Duddar, Las Bela District, Balochistan.

to visit those sources and to obtain samples from them for use in comparative analyses. This could only be accomplished by implementing a strategy of extensive geologic field work (Law 2008b). In a region as vast and diverse (geographically, geologically, culturally and politically) as northwestern South Asia this was an enormous undertaking, but one that was absolutely essential to the success of my research (Figure 3.2). I realized early on that I would need to work in close collaboration with Pakistani and Indian geologists (Figure 3.3). The first and most obvious reason is because geologic materials (their properties,

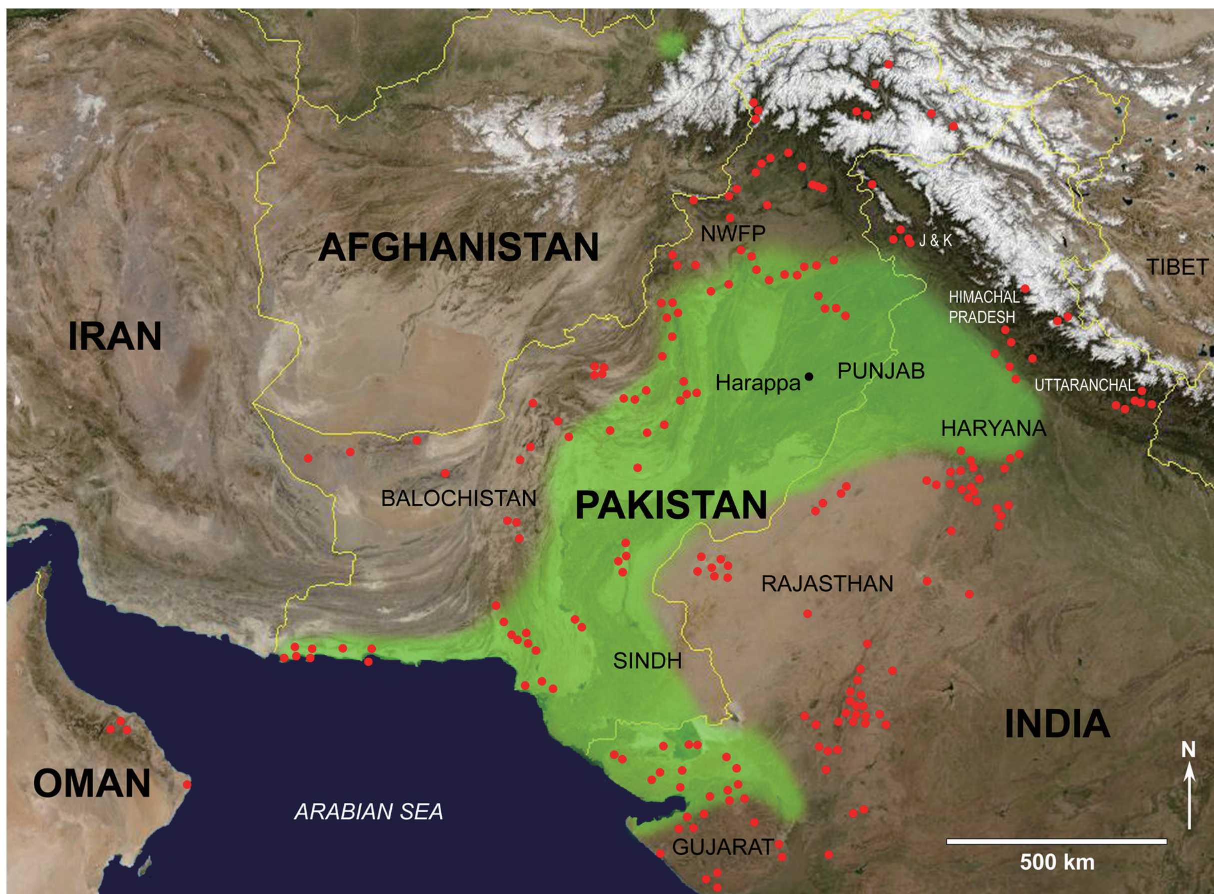



**Figure 3.4** Locations (indicated by red dots) sampled ca. 2000-2010. The green shaded area represents the approximate extent of the Indus Civilization (ca. 2600-1900 BC).

the processes that create them and their economic uses) are the focus of their discipline. Field geologists know their research areas intimately and, in the course of their surveys, often see and note old mines, working areas and sometimes even archaeological sites. Geochemists and economic geologists can provide valuable insights into the nature, variability and locations of mineral deposits and it is often the case that source samples for initial analyses can be acquired from their existing collections. Finally, the disciplines of archaeology and geology share many common features (stratigraphy, time depth, change) and most geologists that I had the privilege to work with have had a great personal interest in the human past.

Since the year 2000, I have visited and/or acquired samples from approximately 200 potential Harappan stone and metal sources in Pakistan, India and Oman (Figure 3.4). From most of them, I was able to collect a representative range of materials so that intra-source and extra-source macroscopic, compositional and/or isotopic variability could be satisfactorily assessed. Sampling strategies varied depending on the type of rock or mineral being studied (details on individual varieties are provided in upcoming chapters) and on the geographic extent over which a "source" occurred (an issue discussed in the next section). In most instances, a minimum of 20 to 25 samples per source were obtained, which is generally considered to be an amount sufficient for making statistically meaningful assessments and comparisons (Malyk-Selivanova *et al.* 1998: 667; Truncer *et al.* 1998: 25). Although no formal collection procedures were employed (such as the laying out of a transect or grid across a deposit and taking samples at predetermined or random intervals), with the help of my colleagues in the geosciences, a concerted effort was made to collect samples that were representative of a deposit, both spatially and

in terms of the full range of macroscopic varieties present in each locality. Whenever possible (and again depending on the type of material), samples were removed from fresh exposures using a geologic hammer rather than taken from loose contexts such as surface scatter or mine tailings.

Field surveys were also essential for reasons that went beyond just compiling a collection of geologic comparative materials. Misidentification/misrepresentation of a rock or mineral deposit sometimes happens, even in the geologic literature. By personally visiting a reported occurrence I was able to confirm or refute its existence and/or to clarify the nature of the material found there. My survey of steatite sources (Chapter 7) illustrates the benefits of employing this strategy. Deposits of steatite were reported in the northern part of the Zhob District, Balochistan at two locations (Ahmad 1975: 135). When I visited the region I found that it was actually chlorite and serpentine, rather than steatite, which occurred at those locations. Field-checking also helped to clarify the nature of steatite deposits worked along the margins of the Peshawar Valley at Jamrud (Abbas *et al*. 1967) and Kund (Qaiser *et al*. 1980). Visits to those deposits revealed that the materials occurring there were of an extremely low-grade and not at all of the quality Harappans used for manufacturing purposes. Lastly, in the course of a field survey previously unpublished sources may be identified, as was the case when I visited several unreported steatite mines in the Las Bela District of southern Balochistan. Although these deposits were well known locally and had apparently been worked for quite some time, to my knowledge no direct reference to them had ever appeared in print.

### Tapping other sources of information: Johris, pansaris and pattarwalas

During my travels across South Asia I picked up a great deal of useful information regarding the sources and uses of rocks and minerals from various *johris*, *pansaris* and people I broadly refer to as *pattarwalas*.

A johri is stone jewelry seller. Although in some instances a group of them have congregated in a permanent location, such as in Jaipur's famous "johri bazaar," in most cases they are individuals who, in advantageous temporary locations, have set up portable display cases (kabats) filled with rings, amulets, necklaces, prayer beads, as well as various loose beads, cabochons and miscellaneous bits of worked and unworked stone. It was from a johri named Sufkara Abbaas (Figure 3.5 A), who had his kabat set up in front of Abdullah Shah Ghazi's tomb in Karachi, that I learned an important steatite, serpentine and chlorite source area discussed by Vidale and Shah (1990) was located relatively close by that city and not, as reported (ibid), near the distant town of Turbat. Mr. Abbaas supplied me with a range raw materials and finished ornaments from the source area, which, using the information he provided, I shortly afterwards visited myself (discussed in Chapter 7). It was during my first research trip to Pakistan in 2000 that Mark Kenoyer showed me the usefulness of talking with johris (Figure 3.5 B) and since then I have rummaged through kabats in places as far flung as Khairpur, Agra and Islamabad (Figure 3.5 C, D & E).

Pansaris are purveyors of traditional "medicinal herbs, crude and refined inorganic medicinal preparations, as well as drugs of animal origin commonly used by the practitioners of indigenous medicine" (Singh 2001: 190). Because rocks and minerals are ingredients in many of their remedies, I made it a point to visit pansari shops in different regions of the study area (such as the one in Bannu, NWFP pictured in Figure 3.6 A) and question the proprietors about the uses and origins of those materials. Often times I would take a set of samples. Figures 3.6 B & C shows the owner of shop in New Attock City, Punjab Province, Pakistan and the group of rocks and minerals that I purchased from him. Many (but not all) of these same materials have been recovered in raw form at Harappa and,



**Figure 3.5** Visiting johris.
**[A]** Mr. Sufkara Abbaas discusses a sample of Wayaro steatite in front of Abdullah Shah Ghazi's tomb in Karachi. **[B]** Dr. Mark Kenoyer looks through a johri's kabat in Karachi. **[C]** Mr. Ashiq Hussain, Khairpur, Sindh. **[D]** A johri in Agra, Uttar Pradesh. **[E]** The author looks through a johri's kabat in Islamabad.

thus, it possible some might have been for medicinal purposes. Pieces of galena (lead sulfide) purchased at this pansari shop and another in Karachi proved to be very informative comparative samples in my studies of Harappan lead artifacts (see Appendix 12.7).

I gathered a tremendous amount useful information from various individuals that I will collectively refer to here as *pattarwalas* or "stone people." Included in this category are the agate bead-makers or *akik-walas* of Khambhat, Gujarat (Figures 3.7 A & B), whose production techniques and material record were documented in detail by Kenoyer, Vidale and Bhan (1991, 1994). I was able to identify many of the same stones that Harappans used among their diverse stocks of raw materials and to learn, if not the exact locations, at least the approximate source areas for important types such as the hard-to-find black and white jasper (Figure 3.7 C). Wherever I went I sought out the carvers of millstones, querns and mortars (Figures 3.7 D & E). They not only provided information on the sources of the raw materials they used but also on the properties that, for grinding purposes, made stone from particular locations preferable to just any old

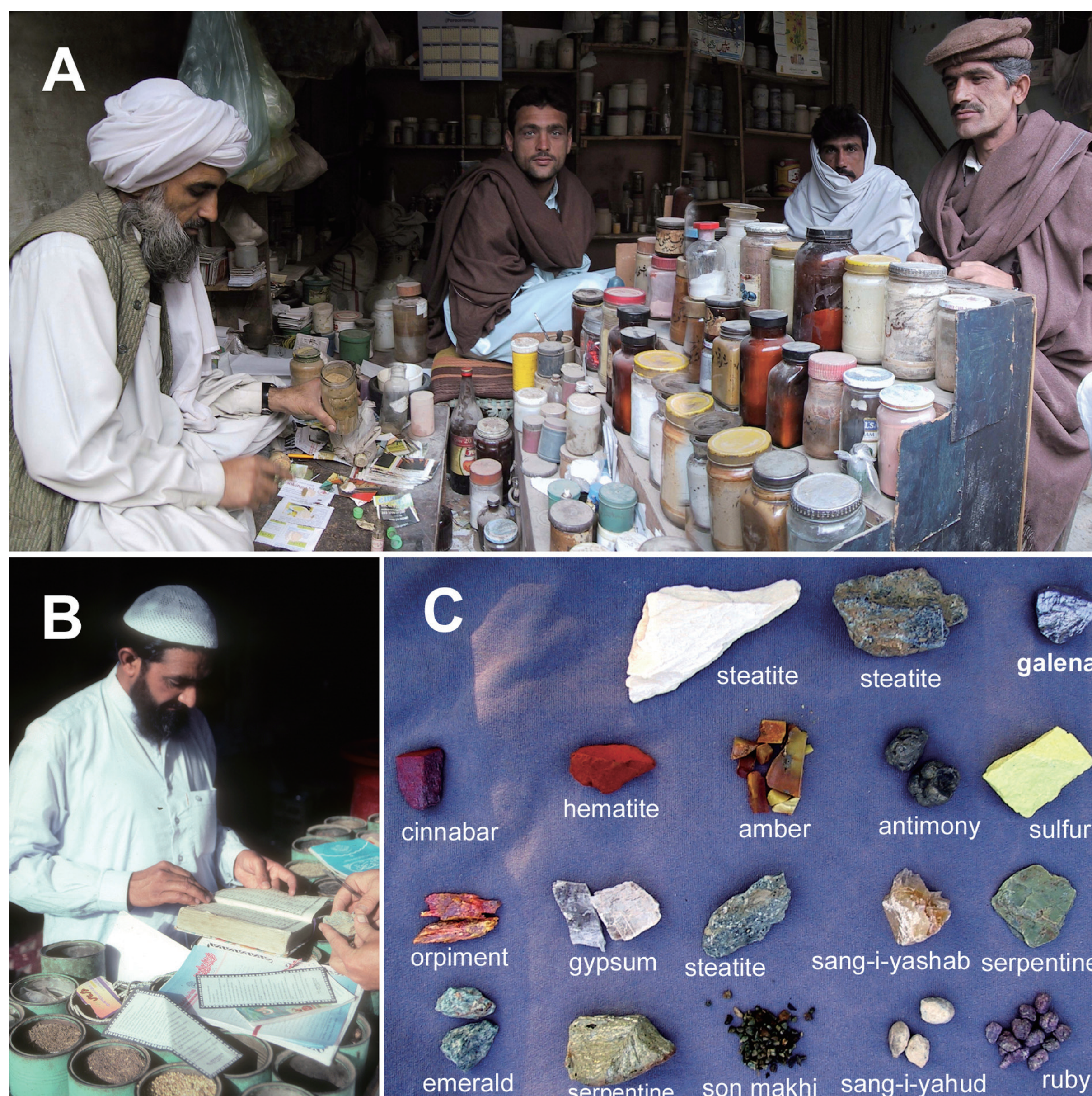



**Figure 3.6** Visiting pansaris.
**[A]** A pansari prepares remedies at his shop in Bannu, NWFP. **[B]** A pansari in New Attock City, Punjab Province, Pakistan consults a manual of traditional medicines. **[C]** The set of medicinal rocks and minerals collected from the New Attock City pansari.

run-of-the-mill rock. Finally, I was fortunate enough to meet by chance individuals in many different places across South Asia (Figures 3.7 F, G & H) who had a deep interest in and knowledge of the geology of their local areas. These pattarwalas were most happy to show me their collections, share some samples, and even personally guide me occurrences of stone that I sought.

#### The "Provenience Postulate" and defining a geographic scale of provenience resolution

Underlying the present study is the assumption known as the "provenience postulate" (Weigand *et al.* 1977: 24). This assumption holds that determining the source of a stone or metal artifact "is possible as long as there exists some qualitative or quantitative chemical or mineralogical difference between natural sources that exceeds the qualitative or quantitative variation within each source" (Neff 2000: 107-




**Figure 3.7** Various pattarwalas.

**[A]** An agate bead-maker in Khambhat, Gujarat. **[B]** "Akik-wala" sign in Khambhat. **[C]** Bead roughouts of black jasper with white bands. **[D]** Millstone carvers in Agra, Uttar Pradesh. **[E]** A women carving querns and mullers, Katmandu, Nepal. **[F]** Mr. Aslam displays a specimen of fossiliferous limestone he collected in Las Bela, Balochistan **[G]** Mr. Bhagat Chang rummages through his collection of crystals from the Parvati Valley, Himachal Pradesh. **[H]** Mr. Malik collects hematite near Shin Kai, North Waziristan.

108). A successful outcome to provenience research is, therefore, largely dependent upon the natural properties of the rock and mineral sources being examined, adequate sampling of those sources (discussed above) and the application of suitable methods for both characterizing materials collected from them and analyzing the resulting data (discussed below). However, an additional factor that has great bearing on the success of a study is the consideration given to the geographic scale on which "sources" are defined and the expectations of provenience resolution that stem from the definition of this scale.

For example, certain types of stone occur as well-circumscribed bodies (outcrops/pockets/zones) of material that, individually, have highly distinctive chemical compositions. Obsidian – a volcanic glass for which the geologic proveniences of artifacts made from it can frequently be resolved down to the level an individual outcrop (Williams-Thorpe 1995), is probably the best example of this type. At the other extreme are materials that occur (either contiguously or intermittently) across broad geographic areas and are fairly homogeneous throughout. Cackler and others (1999) had difficulty differentiating individual chert outcrops in northern Belize because they were all, in essence, part of a single extensive geologic formation. Such a situation, when it occurs, need not always mean that the geologic provenience of an artifact is irresolvable. A "source" can be defined as either a single location or a collection of many locations in "geographic space" (Neff 1998: 116). Depending on the extent of the study area and the diversity of the geology within it, the scale at which a "source" is defined may be expanded to include materials sampled from multiple geologically related locations.

The current examination of Harappan acquisition networks involves numerous rock and mineral types and multiple scales of provenience resolution. The locations where gem-quality vesuvianite-grossular garnet (Chapter 9) and high-quality agate (Chapter 8) can be found are limited in number and in geographic size. Deposits of steatite (Chapter 7) and limestone (Chapter 11), on the other hand, are much more numerous and occur over extremely broad areas. Extensive sampling, characterization and analysis of the latter two materials have indicated that, in some instances, "sources" are best defined at a regional scale. For a material like steatite it may, in the end, only be possible to make a statement such as "the stone that these artifacts are composed of appears to have been derived from deposits located in the NWFP of northern Pakistan." For steatite artifacts from a site situated within that region, like Sarai Khola, this would provide little information other than the material was probably acquired locally. However, in terms of Harappa – a site for which potential steatite sources lay roughly 300 to 900 km away in all directions, this level of resolution is more than sufficient to provide valuable insights into the extent and directions of long-distance resource acquisition networks.

## METHODS OF MATERIAL IDENTIFICATION AND CHARACTERIZATION

In this section, I review the various methods that were used to identify and/or characterize the archaeological and geologic materials examined for this study.

### Visual inspection/comparison and basic mineralogical testing

The 56,000+ stone and metal artifacts recovered during HARP excavations were initially classified by rock or mineral type based on visual inspection by HARP co-director Dr. Mark Kenoyer, who has had nearly 40 years of experience examining lithic materials from archaeological sites in South Asia. For this study, I re-examined the majority of

these artifacts primarily to familiarize myself with the range of materials found at the site but also to locate artifacts for which initial identifications needed to be revised or clarified. Illustrated rock and mineral handbooks and field guides (Pellant 2002; Pough 1988) were especially valuable tools in this effort. Direct comparisons were made between artifacts and geologic samples that I had collected from sources around the Greater Indus region. In May of 2000, with the permission of the Director-General of Archaeology and Museums, Government of Pakistan, I assembled a "traveling" set of samples that contained 200 rock and mineral artifacts from Harappa (all of them small non-diagnostic fragments) representing the full range of material varieties and sub-varieties present at the site. These archaeological samples were compared to geologic samples in the extensive collections housed at the Geological Survey of Pakistan's museum in Quetta, the Department of Geology, University of Peshawar and the Pakistan Museum of Natural History in Islamabad. Numerous professional geologists from these institutions generously provided their expert assessments of the identities and the probable origins the various rock and mineral artifacts in the set. Their identifications enabled me to plan a comprehensive field survey for the purpose of collecting my own geologic samples for comparative analyses.

Simple, non-destructive mineralogical tests were conducted on a number of archaeological samples. The most common test used was that to determine a stone artifact's *density*, which "is a fundamental and characteristic property of each mineral and, as such, is an important determinative property" (Rapp 2002: 21). The density of a mineral is expressed as its *specific gravity* (SG) – the ratio of its weight to the weight of an equal volume of water. A Hanneman direct reading specific gravity balance was used at Harappa to make SG measurements on several hundred artifacts. Another basic test used was that of a mineral's *hardness*, that is, its resistance or susceptibility to abrasion (scratching) relative to ten minerals on an ordinal scale first developed by Friedrich Mohs in 1812 (Appendix 3.1). Mineral types that resembled one another could often be differentiated using a simple scratch test. For example, a translucent green flake composed of vesuvianite-grossular garnet (hardness ≈ 7) will scratch feldspar (hardness 6) and so can be easily be distinguished from an identical looking serpentine flake (hardness ≈ 4), which will not.

#### X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) analysis enables one to unambiguously determine the identity of crystalline substances (Henderson 2000: 10). Over 100 rock and mineral artifacts from Harappa were characterized using this technique, which involves bombarding a small amount of powdered rock sample with X-rays so as to cause the electrons within it to vibrate. The vibrating electrons reflect a portion of the X-ray radiation as waves that reinforce themselves in an effect called *diffraction* (Klein and Hurlbut 1977: 277). The patterns that the diffraction effects create are recorded and provide precise information about the atomic structure(s) of the mineral(s) within the sample. It is the only technique used here that can accurately distinguish between mineral *polymorphs* (minerals sharing the same chemical composition but having different crystal structures). For example, quantitative data on the abundance of silicon dioxide in a sample can be obtained using electron microprobe analysis (discussed below), but only with XRD is it possible to determine which polymorph (*quartz*, *tridymite* or *cristobolite*) it is (Henderson 2000: 11).

The majority of the XRD analyses made for this study were conducted at the at the S. W. Bailey X-ray Diffraction Laboratory, Department of Geoscience, University of Wisconsin-Madison on either a Scintag PADV X-ray diffractometer or a Rigaku Rapid II X-ray diffraction system. Diffraction data were output in digital form and interpreted using the program

JADE 6.0. Some analyses were made at the Center of Excellence in Geology, University of Peshawar on an older instrument that did not possess a computer interface. The XRD patterns were recorded on paper "strip-charts" and the peak positions and relative intensities had to be manually measured and recorded. These data were then interpreted using mineral phase search manuals published by the International Centre for Diffraction Data. Both the Madison and the Peshawar diffractometers were run at 40 kv and 30 ma and, for most samples, scans were run at a 2-theta angle from 5° to 65° with a .02° step size and a .25 second count time.

Using the old XRD in Peshawar and the Scintag XRD in Madison required that a small amount of material be ground to a fine powder for analysis. Thus, because it was a destructive method, only archaeological raw material debris fragments were analyzed using these instruments. In 2009, the Rigaku XRD was installed in Madison. With this instrument, artifacts can be directly X-rayed without powdering. This has permitted the mineralogical composition of a number of small artifacts to be non-destructively determined. The Rigaku XRD employs a molybdenum target and so the 2-theta values of spectra output by this instrument are different from those made using the Scintag XRD, which employs a copper target (the peak patterns are identical, however). In one instance, I modified the Rigaku-made spectra of steatite microbeads (Appendix 7.14 Figure 2) to be comparable to the Scintag-made spectra of experimentally heated steatite chips (Appendix 7.12 Figure 3). The remaining Rigaku-made XRD spectra included in this study (these are individually noted) are unmodified.

### Electron microprobe analysis (EMPA)

Electron microprobe analysis (EMPA) is both a method with which to acquire compositional data on solid materials as well as a powerful micro-imaging tool (Reed 2005). Samples are affixed in epoxy within a tubular analysis cartridge and then a flat surface is ground, polished and given a thin carbon coating. Upon this surface the "probe" can focus a beam of electrons on an analytical area as small as 1 $\mu m$ or micron (0.001 millimeter). This makes it a useful tool for examining rocks having multiple mineral phases and minute inclusions. Chemical characterizations can be done using either the energy dispersive spectrometry (EDS) or wavelength dispersive spectrometry (WDS) capabilities of the probe. EDS measures the X-ray energy emitted from the area under the beam of electrons and permits quick reconnaissance and qualitative chemical characterizations of materials (Lund 1994). WDS measures electrons diffracted by the crystal structure of the material under the beam (Lund 1995). When calibrated with known standards, highly accurate quantitative chemical data can be obtained using WDS. Micro-imaging of materials using backscattered electrons (BSE) works on the same principle as scanning electron microscopy. All EMPA of archaeological and geologic samples in this study was conducted under the direction of Dr. John Fournelle at Department of Geoscience, University of Wisconsin-Madison on either a Cameca SX50/51 electron microprobe or a Hitachi variable-pressure scanning electron microscope (VP-SEM) with EDS capability.

### Spectrometric analysis

Spectrometric (spectroscopic) analysis includes many different methods and types of instruments (Pollard and Heron 1996: Chapter 2). Highly accurate data on the elemental composition of a substance can be collected by observing the spectrum of light emitted when the atoms composing it are excited (atomic emissions spectrometry). Elemental as well as isotopic data may be obtained by directly detecting ionized atoms that have been separated according to their mass-to-charge ratios (mass spectrometry). Excitation or ionization of a sample

for analysis can be achieved by various means but the use of an inductively-coupled plasma (ICP) torch is becoming increasingly common (Taylor 2000).

Spectrometric analyses were conducted on artifacts and geologic samples composed of alabaster, limestone and various metals (lead, silver and copper). Limestone and metals were analyzed using the two ICP spectrometers at the Laboratory for Archaeological Chemistry (hereafter LARCH), University of Wisconsin-Madison, under the direction of Dr. T. Douglas Price and Dr. James Burton. The first instrument was an Applied Research Labs Model 3520 inductively-coupled plasma - atomic emission spectrometer (ICP-AES), which can detect and quantify dozens of elements at sub-parts-per-million concentrations (see Burton and Simon 1993 for elemental detection limits and precision typical of this instrument). The second was a Finnegan MAT ELEMENT I high resolution, magnetic-sector inductively coupled plasma-mass spectrometer (ICP-MS), which can obtain elemental and isotopic data at concentrations in the parts-per-quadrillion range. Full details regarding sample preparation and analysis, which varied according to the material being analyzed, are provided in Chapter 11 for limestone and in Chapter 12 for metal artifacts.

The analysis of certain artifacts and geologic samples required the use of spectrometers not available at the LARCH. The sulfur isotope compositions of alabaster (Chapter 10) and lapis lazuli (Appendix 4.4) were determined by Dr. Chris Eastoe at the Isotope Geochemistry Laboratory, Department of Geosciences, University of Arizona using a continuous flow isotope ratio mass spectrometer (CFIRMS). High precision strontium isotope assays of alabaster samples were made by Drs. Joel Blum and Andrea Klaue at the Department of Geosciences, University of Michigan–Ann Arbor, using a thermal ionization mass spectrometer (TIMS). Full details on these instruments, sample preparation and analysis are provided in the Chapter 10. A small number of lead samples examined in this study were analyzed on a Neptune multiple-collector inductively-coupled-plasma magnetic-sector mass-spectrometer (MC-ICP-MS) by Dr. Emily Peterman at the W.M. Keck Isotope Laboratory in the Earth and Marine Science Department, University of California-Santa Cruz.

### Instrumental neutron activation analysis (INAA)

Instrumental neutron activation analysis (INAA) – a highly accurate and precise method for quantifying the major, minor and trace element compositions of materials, has been used by archaeologists around the world in efforts to determine the proveniences of a wide range of artifact types (Glascock and Neff 2003). In South Asian archaeology, this technique has, up until now, been exclusively applied to provenience studies of ceramic artifacts such as figurines (Possehl 1994), stoneware bangles (Blackman and Vidale 1992) and pottery (Méry and Blackman 1999; R.P. Wright 1984). For this study, INAA was used to characterize geologic samples and artifacts composed of chert, steatite, agate-carnelian, vesuvianite-grossular garnet and limestone.

All rock samples subjected to INAA were prepared for analysis at the LARCH. Fresh, unweathered material was preferred for analysis. For geologic samples, either a small chip (approximately one gram) was struck from a freshly broken surface toward the interior of the sample and then crushed into a coarse powder with a steel mortar and pestle or, for softer stone (steatite and some limestones), a tungsten carbide drill was used to burr-off the exterior surface of a small area on a sample and then drill directly into the fresh material, creating powder in the process that could used for analysis. Drill bits were carefully cleaned after each was sample was taken. Should contamination from the bit itself have occurred, it would be recognizable as a tungsten "spike" in the INAA spectrum during analysis (Truncer *et al.* 1998: 29). Archaeological samples

were first cleaned in an ultrasonic bath of purified water. Removal of material was dependent on the size nature of the artifact. Generally around 0.5 to 1 gram of material was chipped off of hard stone artifacts and lightly pounded in the steel mortar into smaller (< 1 mm) pieces. The pieces were examined under low magnification and those that were free of cortex, patina or other surface features were selected for analysis. Artifacts made of softer stone were sampled using the tungsten drill described above. For both geologic samples and artifacts, exactly 200 mg (± 1 mg) of sample was loaded into polyethylene vials. Using a diamond scorer, sample numbers were etched onto the vials, which were then sealed by friction welding.

Sample analysis was conducted at the University of Wisconsin's Nuclear Reactor (UWNR) research facility by the team supervised by lab director Robert Agasie. INAA provides precise data on the elemental composition of a material. Elements within samples are first made radioactive, or *activated*, by exposing them to a neutron flux, after which the gamma ray emissions produced as radioactive elements decay were detected and counted (see Glascock and Neff 2003 for full details on this technique). A series of vials containing a standard (Canadian Centre for Mineral and Energy Technology Reference Soil Sample SO-4) were irradiated with the samples to calibrate for variations in exposure to the neutron flux (Robert Agasie and Kevin Austin, UWNR *personal communication*). Depending on an element's half-life, different irradiation and count times were necessary. For the "short" count at the UWNR, each vial was irradiated for 3 seconds and, after a 15 to 16 minute decay time, a 300 second count was performed. For the "long" count, sample vials were irradiated for 7,200 seconds and, after a decay time of approximately seven to ten days, a 3,600 second count was performed. The UWNR facility employs a high purity Ortec Geranium Detector coupled with a PCAII PC-based multi-channel analyzer to detect specific gamma ray emissions emitted by the irradiated samples to determine the amounts of individual elements present within them. The fractional proportions of the elements detected in each sample were reported in parts per million (ppm). After the results were screened of elements that failed to be detected in all samples or had high count-rate standard deviations, the data could be subjected to multivariate statistical analyses.

## METHODS OF DATA ANALYSIS

The application of the characterization methods outlined above to the different sets of archaeological and geologic samples examined for this study resulted in large amounts of raw, highly varied types of quantifiable data. Because these results were used to determine the probable geologic provenience of stone and metal artifacts (and, ultimately, to support statements about the behaviors of ancient Harappans), the methods by which they were evaluated had to be carefully chosen. Much has been written regarding the numerous approaches to the analysis of quantifiable archaeological (Baxter 1994, 2003; Shennan 1997) and geologic data (Davis 1986). In this section, I discuss the methods utilized in this study and the reasons for choosing to employ them.

### Preliminary data analysis / bivariate plotting

Prior to any statistical manipulation, multiple combinations of isotopic or elemental (after being log normalized) values in a dataset were compared on simple bivariate plots using the program DataDesk 6.0. This exploratory procedure was conducted to determine if, at this initial level, groups of samples from different geologic sources could be clearly differentiated from one another. For sets composed of isotopic data, like those produced for alabaster (Chapter 10) and lead (Chapter 12), this was indeed

possible through bivariate (and in some cases even univariate) plotting of measured values alone. For other datasets, such as that for limestone (Chapter 11), bivariate plots of selected elemental values produced reasonably good separation between sources but multivariate analysis was found to work somewhat better. In such instances, both methods will be presented for comparison. For most of the rock or mineral datasets, however, these preliminary analyses indicated that groups of samples belonging to different geologic sources could not be easily distinguished using simple bivariate plots alone. More robust, multivariate approaches were required.

## Multivariate approaches

### *Choice of methods*

For the purposes of study, canonical discriminant analysis (CDA) was deemed the most suitable method for using multivariate data to differentiate sets of samples from various geologic sources and to assign provenience to archaeological samples. CDA is different from other statistical approaches such as principle component analysis or cluster analysis – two methods widely employed in provenience studies of archaeological ceramics (Glascock *et al.* 2004), in that it begins with the presumption that a dataset already has a well-defined structure (Baxter 1994: 185). There is no need to assess patterns of variance or clustering in an effort identify structures that may (or may not) represent meaningful groups, simply because groups with known members have already been defined in the dataset. Here, the known groups are the sets of geologic samples that I have personally collected from sources across Pakistan and India. Although the degree to which it is possible to differentiate the various geologic sources within a dataset is initially unknown, there is never any ambiguity whatsoever as to whether or not the samples representing those sources actually belong to them. When groups are known *a priori*, CDA is the most suitable multivariate technique to use (ibid.: 81). It has been used in provenience studies of several of the same materials examined in this study including steatite (Truncer *et al.* 1998), chert (Craddock *et al.* 1983) and limestone (Holmes and Harbottle 2003).

Certain situations arose throughout this study for which the use of a supplementary multivariate statistical method proved to be worthwhile. For instance, a large set (n = 141) of archaeological steatite from Harappa was analyzed (Chapter 7) and it is useful to know if multiple geochemically distinct groups of materials may be represented among the samples making up that set. Cluster analysis was chosen as the appropriate method with which to evaluate this possibility. This method, which actually encompasses a many different techniques (Baxter 1994: 140), can be used in tandem with CDA as a way to validate and graphically complement observed clusters of unknown samples that, in the case of stone artifacts, may be from the same geologic formations (ibid.: 165, 204-206).

All multivariate analyses were made using the statistical program SPSS 11.0.

### *Canonical Discriminant Analysis*

Canonical discriminant analysis (CDA) was used to make geologic provenience determinations for rock and mineral artifacts in five of the upcoming chapters. For details on the complex mathematics underlying this method one should seek out Michael Baxter's treatises on statistical applications in archaeology (Baxter 1994, 2003). Here, I provide general overviews of the two main features of CDA: discrimination and classification.

#### *- Discrimination*

CDA makes two important presumptions of a dataset: 1) that it is composed of distinct groups whose individual members are known and 2) that it contains all possible groups (Baxter 1994: 185-186). During the analysis of a dataset, one or more linear combinations of variables called *discriminant functions*

are generated, each of which are intended to produce the maximum degree of separation (discrimination) possible between the groups of individual cases being assayed. If a set is composed of two groups then just one discriminant function is possible as there is only a single dimension between them that can be evaluated. Analysis of datasets made up of larger numbers of groups results in the generation of multiple functions because additional dimensions can be considered. Displaying the results of analyses involving three or more groups in a two dimensional format is accomplished by creating a bivariate plot of the dataset using the *first* and *second* functions (which are the first and second most significant discriminators) as the axes. Individual members of a dataset are plotted by their *discriminant scores*, which are the values that result when discriminant functions (unstandardized canonical discriminant function coefficients) are applied to each case. In essence, CDA collapses the multiple measurements made for a case down into a single variable (Davis 1986: 479). The *optimal* end result is a scatterplot on which each group is represented by a separate distinct cluster of datapoints (cases), all of which actually belong to the groups they are in.

Optimal separation between groups of samples in a dataset is not always achieved, however. The clusters of datapoints representing a group may overlap with one another – sometimes considerably. Visual examination of scatterplots is the really not the best way to accurately assess how well groups were differentiated using CDA. Discrimination success is better evaluated through "cross-validation" (Baxter 1994: 204). SPSS 10.1 has a cross-validation feature called "leave-one-out" classification. In this procedure, each member of the dataset is omitted from the group it belongs to and classified (a process discussed in the following section) in relation to the dataset as an *ungrouped case*. A percentage is generated based on the number of cases in the dataset that were correctly assigned to the groups that they actually came from. This percentage provides a general indication of how good group separation is and a way to compare discrimination success from different stages of analysis.

*- Classification (and misclassification)*

The same discriminant functions that were generated to differentiate known groups can also applied to individual cases of unknown origin to classify them according to which group or groups they most closely resemble. These "unknowns" (stone artifacts as well as the geologic samples left out of their groups for cross-validation purposes) are treated *ungrouped* cases and each is placed (according to its discriminant scores) on a bivariate plot in relation to the defined groups of a dataset. The point in space where the mean of a group's members' discriminant scores is situated is called a *group centroid*. An ungrouped case's similarity/dissimilarity with the two or more group centroids in a dataset is established in terms of *Mahalanobis distance* – a statistical measurement that takes into account correlations between variables (Baxter 2003: 70). An individual case shares one Mahalanobis distance value with each group and it is classified as belonging to (or predicted to most likely belong to) the group for which that value is the smallest.

Two quick caveats need to be made regarding CDA classifications/predictions. First, because the method presumes that a dataset contains all possible groups, every ungrouped case considered receives a *predicted group membership* (PGM). This does not mean that the cases definitively belong in the groups that they have been assigned to or, for that matter, to any of the other groups in a set. There is always the chance that the classification for an archaeological sample (ungrouped case) will change when materials from additional geologic sources (known groups) are eventually added to the dataset. Secondly, there is the possibility that an artifact may also be misclassified even when the

source from which it derived is represented as a group in the dataset. Misclassification might occur because of poor separation (discrimination) due to geochemical similarities between the sources being considered and/or because an artifact is an outlier that is situated nearer to the centroid of a source different from its own. In cases when the *first* PGM is questionable, it is sometimes useful to examine the *second* PGM (determined by the second nearest group centroid). In certain cases it *could* be the actual source. Classifications made throughout this book are evaluated on a case-by-case basis in light of overall cross-validation success percentages as well as, occasionally, second PGM determinations.

***Cluster Analysis***

"Cluster analysis is the generic term for a wide range of methods for discovering homogeneous groups or clusters in a set of data" (Baxter 2003: 90). The various approaches employed in this study fall into a category of methods known as *hierarchical clustering*, which essentially works by either building up (agglomerative) or breaking down (divisive) a dataset into groups based on different measurements of their members' similarities/dissimilarities. Discussions of the different algorithms and distance measurements that may be applied to a dataset to produce clusters can be found in any one of several excellent books written on statistical analysis in archaeology (Baxter 1994, 2003; Shennan 1997). Although some consider the *average linkage* technique to one of the better hierarchical methods (Shennan 1997: 254), there is no one method that is clearly to be preferred over others. Multiple methods can be applied in an exploratory manner to observe how they compare. If the "structure in the data is reasonably clear and captured by all of the competing methodologies" then one may be "reasonably confident that a revealed structure is 'real'" (Baxter 1994: 160).

The result of a cluster analysis (CA) is most commonly displayed as a *dendrogram* – a series of connected straight lines branching out like limbs on a tree. The terminal ends of the branches signify individual cases. Similarity between any two given cases is represented by their distance to each other along the branches of the tree rather than by their proximity to each other on its terminal end. Determining the number of separate clusters that are represented on a dendrogram (in a dataset) is very much a subjective endeavor and, once again, can be facilitated by comparing multiple clustering strategies.

## CHAPTER CONCLUSION: STATEMENTS OF PROVENIENCE

For this study, an effort was made to be as comprehensive as possible with regard to locating the geologic sources that Harappans potentially acquired rock and mineral resources from, to collect representative samples from as many of those sources as possible; to define the best scale of provenience resolution, to employ the most appropriate methods of material identification and characterization and to choose those analytical methods that were best-suited for examining the different types of data that were produced. Nonetheless, <u>any</u> statement made in this book regarding the geologic provenience of a stone or metal artifact should always be considered as *provisional*. The study area is vast and the possibility exists that the true source of a particular material may not have been located and/or sampled. Artifact provenience determinations may need to be revised when additional sources are eventually considered. The strongest statement of provenience that can be made at present or, for that matter, at any time in the future (regardless of how many sources and samples are eventually incorporated into a dataset) is: "given all of the sources examined, artifact X appears most chemically (or isotopically or mineralogically) analogous to geologic samples analyzed from source

Z or from source region Z." Still, although always provisional, such a statement and the data that it is based upon can be used to construct a compelling argument for a link between Harappa and a specific source area.

Prior to constructing such arguments, however, it is first necessary to present Harappa's rock and mineral artifact assemblage in detail and examine its spatial and temporal distribution at the site.

# CHAPTER 4

# THE ROCK AND MINERAL ARTIFACT ASSEMBLAGE AT HARAPPA

## CHAPTER INTRODUCTION: ORGANIZING AND PRESENTING THE ROCK AND MINERAL ASSEMBLAGE

The rock and mineral artifact assemblage at Harappa is large. More than 56,000 individual items made of stone or metal have been tabulated since excavations by the HARP began in 1986. It is also very diverse. Around 40 distinct kinds of rocks and minerals are represented among the materials recovered at the site (Law 2001, Law 2005b: 113-114). The first purpose of this chapter is to organize and present this huge and highly varied body of data in a way that allows it to be examined on multiple scales. In order to make that possible, the different materials in the assemblage are placed into manageable categories that I call "varieties." Each variety is then discussed in terms of the general range of material types it encompasses, the quantities in which those materials are found at Harappa, how they are spatially distributed across the site and the chronological contexts with which they are associated. In the concluding sections of this chapter, all of that information is evaluated and then used to address one of the stated aims of this study, which is to examine Harappa's rock and mineral assemblage as a single entity composed of many different elements that may vary over space and time.

The eight chapters that immediately follow this one each focus on identifying the acquisition networks of one particular rock and mineral variety used at Harappa. The second, but no less important, purpose of this chapter is to provide pertinent details on the remaining varieties in the assemblage, which are not featured elsewhere in the book. Although these other varieties are not presently the subject of geologic provenience studies, simply identifying where in the Greater Indus region (Figure 4.1) they do and do not occur provides valuable information regarding the probable extent and direction of Harappa's rock and mineral acquisition networks during the chronological phases from which they were recovered. Doing this also helps to draw attention to specific regions and/or types of geological formations from which multiple varieties of rocks and minerals may have been derived. Although the results of the geologic provenience studies conducted for this study sometimes indicate a certain material variety or varieties probably came from a particular region, it is useful to know what other rocks and minerals found at the site were available in that region and may have also come from that region.

The final purpose of the chapter is to provide details relating to the identification or characterization of certain rocks and minerals in the assemblage. Many material varieties could be easily identified on the basis of their macroscopic appearance alone. For others, however, some sort of assessment of their physical properties, whether by using a simple method (such as specific gravity or hardness testing) or a more sophisticated one (XRD or EMPA), was required. Also, the nature and correct identification of a few varieties of stone in the assemblage has been (and will probably continue to be) debated. The characterizations made here can at least help to narrow down the probable material types of those varieties and their likely geologic source or sources.




**Figure 4.1** Regions, sources and sites discussed in this chapter.

## DETERMINING THE COMPOSITION OF THE ROCK AND MINERAL ARTIFACT ASSEMBLAGE

The first task was to determine the composition of Harappa's rock and mineral artifact assemblage by establishing exactly what kinds of stone are present at the site and in what quantities. To accomplish this, three information sources were used: tabulation data, the Harappa database and examinations and analyses conducted specifically for this study.

Almost every artifact recovered at Harappa has been individually examined by HARP co-director Dr. Mark Kenoyer and, based on its material and/

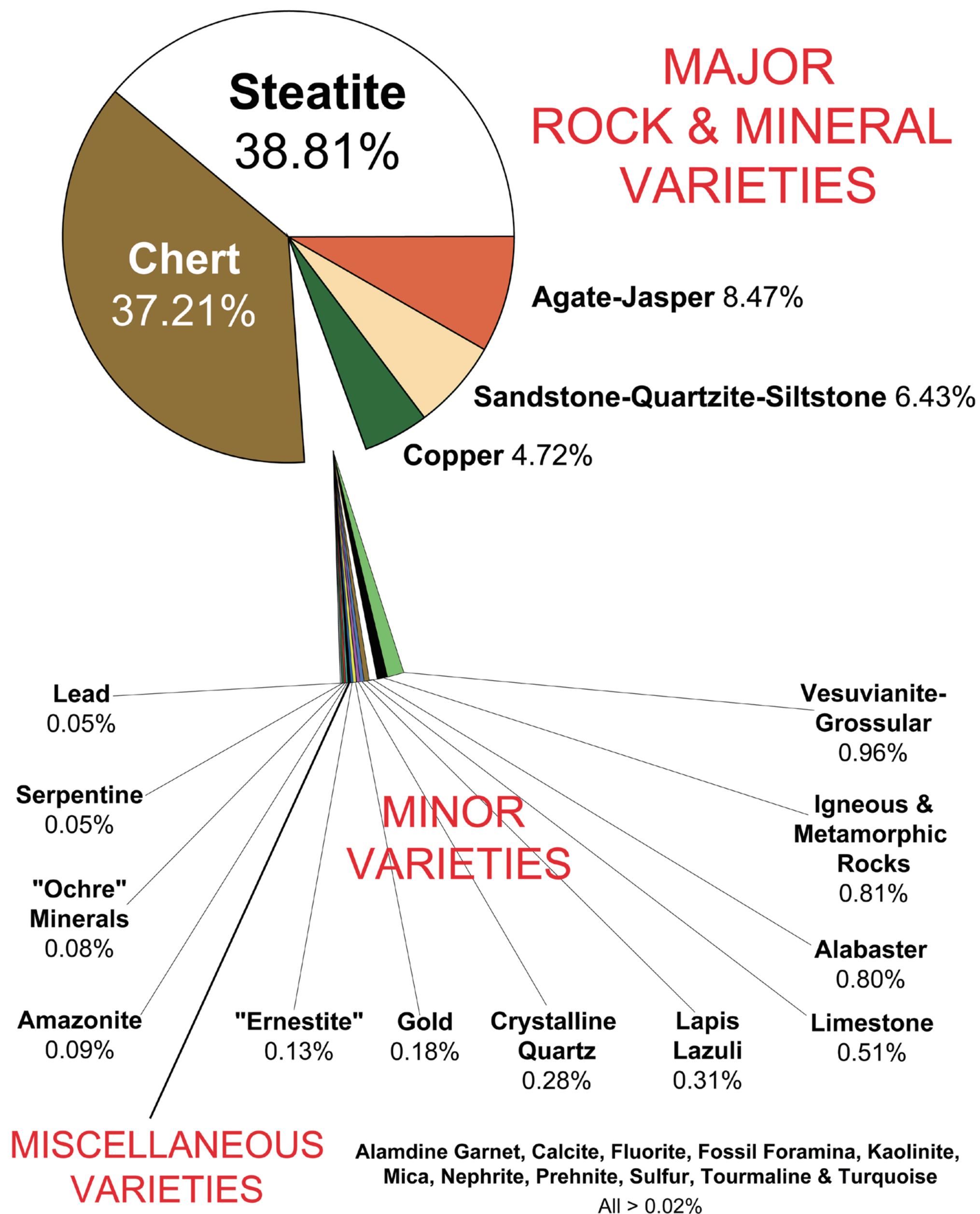
or technological attributes, placed into a *tabulation database* that he and Dr. George Dales developed with input from other project members (Meadow and Kenoyer 1992). As of 2005, this database contained 125 categories for objects made of stone or metal. For certain categories, the description of a tabulated artifact's material type is very explicit, such as those in which a "gold bead" or an "unmodified chert flake with 100% cortex" would be placed. Other categories are necessarily more generalized, such as the one for "truncated conical amulets," which are known to be made of any number of materials, not all of them stone.

When an artifact's material type was not determinable using tabulation data alone, the *Harappa database* was turned to. This FileMaker Pro database, which was developed by HARP member Sharri Clark and is maintained by HARP director Dr. Richard Meadow, contains a wealth of information relating to excavated materials including photographs of many objects, a data entry field listing specific material types and a field for descriptive entries that frequently provide additional information on an artifact's physical attributes. Material descriptions entered into this database were taken directly from the artifact recording sheets used by Mark Kenoyer as he examined objects after excavation and/or conservation. Material type for objects such as truncated conical amulets could usually be gleaned from this source. However, the Harappa database was not developed until the mid-1990s and updating it is an on-going and time-consuming process. Priority is given to registered objects and those accessioned into the Harappan Museum. Many artifacts, especially those from early excavation seasons at Harappa, have not yet been added to it.

In those instances where material type could not be determined using the tabulation database or the Harappa database, artifacts were examined first-hand and categorized based on information gained from either visual inspection or one of the analytical methods employed in this study. More than 100 examples were characterized using X-ray diffraction (XRD) analysis. Whenever possible, artifacts subjected to this destructive technique were chosen from among the large sets of materials recovered during surface surveys. Appendix 4.1 lists the major mineral phases for all samples characterized in this way, as well as some minor phases detected using electron microprobe analysis (EMPA). Rather than displaying the XRD peak profiles obtained for each of the 100 plus samples (a large portion of which are absolutely identical), scans representative of the various material types (and sub-types) that were identified are provided in Appendix 4.2. Some artifacts were characterized using EMPA or specific gravity testing. Those results are presented in the body of the text of this and subsequent chapters.

After all information on material types was gathered, it was decided that the artifacts should be re-categorized in a way that would help to make a very large dataset more manageable, but still highlight the assemblage's diversity and patterns of material usage within it. They were therefore re-organized into groups that I call "varieties." The majority of varieties still feature single material types, such as lapis lazuli or amazonite, which are macroscopically and mineralogically distinctive. Others varieties, however, were created by lumping or splitting material types. For example, rocks known as microcrystalline silicates, although mineralogically alike (all are basically quartz), exhibit enormous macroscopic variability and could have easily been divided into a dozen separate varieties. In the end, however, only two were defined – cherts and agate-jaspers, which were based not only their macroscopic differences but also on their functional attributes (more on this below). In other instances, several rocks or minerals types were lumped together based on a shared attribute, such as in the case of "lead," which includes finished lead artifacts as well as the various raw ore sulfides, oxides, of carbonates of lead found at Harappa. Admittedly,

**Figure 4.2** The composition of Harappa's rock & mineral artifact assemblage. Percentages based on 56350 tabulated rock and mineral artifacts.




many of choices made when defining varieties were somewhat subjective and groupings could have been made any number of other ways. However, for the purposes of this study they are quite suitable.

With the varieties of rocks and minerals defined, percentages of each one present in the assemblage were generated based on the number of individually tabulated artifacts. A chart depicting the overall composition of Harappa's rock and mineral artifact assemblage can be seen in Figure 4.2. All material varieties that compose more than 1% of the overall assemblage are defined as one of the *major* rock or mineral varieties. All those for which there are more than ten examples in the assemblage, but that make up less than 1% of the overall total, are defined as the *minor* varieties. *Miscellaneous* rock or mineral varieties are those for which ten or fewer examples have been recovered at Harappa. The designations *minor* and *miscellaneous* do not necessarily mean that Harappans considered those materials to be less

important, less desirable or less requisite than any of the more abundant stone types in the assemblage. On the contrary, it is probable that many of the less common varieties were highly valued. A material such as gold almost assuredly was. Differences in the relative abundances of the rock and mineral types might be due to recycling or re-use of certain materials and not others, variations in the amount of debitage produced when possessing different types of stone, or any number of other factors besides or in addition to frequency of use.

## MAJOR ROCK AND MINERAL VARIETIES

Over 95% of the artifacts in Harappa's rock and mineral assemblage are composed of one of five varieties of rock or mineral. These are referred to as the *major* varieties (Figure 4.3). Examples of each one have been recovered in abundance on every mound, in almost every excavation trench and from every chronological phase at Harappa.

### Steatite

Nearly 40% of all lithic artifacts from Harappa have been classified as *steatite*. Full details regarding the origin, potential sources, geologic provenience and use of this stone during the Indus period are presented in Chapter 7. Here, I discuss the issues relating to the identification and classification of this material at Harappa.

Commonly known as "soapstone," steatite is a "soft" (Mohs' scale hardness of 1 to 2.5) metamorphic rock that is primarily composed of the mineral talc (hydrous magnesium silicate) but may contain a wide range of secondary minerals. Its visual appearance is highly variable. The color in a single hand specimen can grade from deep black to pure white with intermediate shades of red, green or yellow. Because it often resembles other soft stones such as chlorite or serpentine, misidentifications can and do occur. For example, "intercultural" style stone vessels from the third millennium BC site of Tepe Yahya in southeastern Iran were thought to be made of steatite until Philip Kohl (1976, 1979) examined them using XRD and determined that most were actually composed of chlorite.

Stone artifacts classified as steatite at Harappa often differ greatly in appearance (Figure 4.3 A). For this reason, the mineralogical characterization of a sample of artifacts representative of the different visual types found there was considered to be essential.

Vidale and Bianchetti (1997) were the first to characterize steatite artifacts from Harappa using XRD. They found that four green-colored fragments were all predominantly composed of talc with occasional secondary phases of quartz or dolomite. For this study, an additional 29 unmodified (not heat treated) fragments of soft stone from Harappa thought to be steatite were analyzed using XRD (Appendix 4.1). Samples were chosen to represent the full spectrum of visual types present at the site (see Figure 4.3 A *top row* for a selection of these). Three representative XRD scans can be seen in Appendix 4.2. Scans for 20 of the samples displayed diffraction peaks for talc alone (Appendix 4.2 A), five showed talc with a minor component of dolomite (Appendix 4.2 B) and four indicated talc with a minor component of quartz (Appendix 4.2 C). Despite their variable appearances, all samples could be characterized as steatite. These results and those of the earlier study provide confidence that artifacts of this variety have been correctly classified.

It is important to note that around 86% of the almost 22,000 steatite artifacts at Harappa have been heat-treated (four heated-treated steatite beads can be seen in Figure 4.3 A *bottom right*). The talc that such artifacts were originally composed of has wholly or partially converted to the mineral *enstatite* (magnesium silicate). In some cases heating may have also resulted in the formation of *cristobalite*

**Figure 4.3** The five major rock and mineral varieties at Harappa.




**A.** Steatite artifacts.
*Top row* - fragments of raw (unheated) steatite debris
*Bottom right* - heat treated steatite beads




**B.** Three main types of chert at Harappa
*Left to right* –
tan-gray (1-3) and
tan-gray *banded* (4),
black-brown (5-8) and
purplish (heated?) chert -/ chalcedony (9 & 10).




**C.** Agate and jasper debris representing just a few of the macroscopically distinct types present at Harappa.




**D.** Siliciclastic rock artifacts. *Left to right*-
Coarse to medium grained sandstone quartzite quern, slate whetstone fragment, various silicified quartzite and fine grained pebbles and cobbles.




**E.** Copper artifacts.
*Left to right* – copper alloy rod fragment, copper alloy lump, chalcocite and malachite.

($SiO_2$). Cristobalite is a high temperature *polymorph* (polymorphs are two minerals sharing the same chemical composition but having different crystal structures) of quartz. A full discussion of this process can be found in Chapter 7. Although the original mineral compositions of these heated artifacts have been considerably altered (technically making them a different mineral – enstatite), for the purposes of this study they are still classified as steatite.

### Microcrystalline silicates

Chert, flint, jasper, chalcedony, agate, carnelian, bloodstone, heliotrope chrysophrase, novaculite, radiolarite, sard and onyx are all terms for closely related (in many cases mineralogically identical) sedimentary rocks. All are composed principally of microscopic crystals of quartz (either granular or fibrous) that form when silica chemically precipitates out of an aqueous solution (Luedtke 1992: 18). Numerous visually distinctive types of microcrystalline silicates are found at Harappa and, when considered in total, they are the most abundant variety of lithic material at the site. However, I have chosen to divide this diverse assemblage into two, albeit still broad, sub-varieties – cherts and a combined category consisting of agates and jaspers (agate-jasper). This division makes chert a close second and agate-jasper a distant third in terms of abundance of tabulated stone artifacts at the site. The decision to define two sub-varieties was based partially on the different macroscopic characteristics of microcrystalline silicates (described below) and partially on the different uses Harappans made of such materials. Chert was used mainly as a material for making tools and cubical weights. Agates and jaspers were primarily stones from which ornaments (mostly beads and pendants) were fashioned. Although some ornaments and other objects made of chert have been recovered at Harappa and numerous agate-jasper tools have also been found (notably in the site's earliest phase), the two material sub-varieties were *typically* used for creating different types of objects.

#### *Chert*

No hard and fast definition exists for the term "chert." Barbara Luedtke (1992) used it in a general way to refer to all microcrystalline silicates. She considered agate, for example, to be a translucent variety of chert (ibid.: 31). George Rapp (2002: 71-72) prefers to differentiate microcrystalline silicates based on their crystal structures – cherts are those with a granular structure while chalcedonies have a fibrous structure. At Harappa, classification has been based mainly on visual characteristics. Chert artifacts are generally defined as those opaque microcrystalline silicates having a color that is either neutral (ranging from light gray to black) or a shade of brown. The one exception to this convention is a type of chert/chalcedony with a purplish hue that was used to make tools during the Early Harappan periods. Artifacts fitting these descriptions make up over 37% of the rock and mineral assemblage. Examples of the three most common macroscopic types – tan-gray (sometimes banded), black-brown and purplish chert/chalcedony can be seen in Figure 4.3 B. Chapter 6 is devoted to examining the acquisition of these chert types.

#### *Agate-Jasper*

If you ask a geologist, mineralogist, gemologist and archaeologist each to define agate and jasper you may very well receive four different answers. The lack of consensus is mainly due to the fact that these types of microcrystalline silicates are so highly variable that they defy any absolute classification (Butler 1995). For this reason, it was decided that the criteria used in this study should be as straightforward as possible. Agates are simply defined as any wholly or partially translucent variety of microcrystalline silicate. Jaspers are those opaque microcrystalline silicates that are of colors other than the ones used above to define chert – generally this means shades of red, green or yellow. In Gujarat and again in Waziristan, I have

seen microcrystalline silicates that grade from jasper to agate in an individual hand specimen. When considered as a single material variety (for reasons explained), agate-jasper comprises 8.47% of the site's rock and mineral assemblage. Not surprisingly though, the use of such broad, encompassing definitions means that artifacts in this category vary tremendously in their visual appearances (Figure 4.3 C).

Although defined here as belonging to the "agate-jasper" sub-variety, some jasper artifacts are dealt with (briefly) in the chapter on chert (Chapter 6). In Chapter 8, INAA is used to compare agate from sources (or proxy sources) in India and Iran to a set of archaeological samples from Harappa and several other prehistoric sites in South Asia.

### Siliciclastic sedimentary rocks

"Siliciclastic" rocks are those composed of *clastic* sediments (materials weathered or broken from pre-existing rocks) primarily derived from *silica*-rich, non-carbonaceous rocks. Rocks of this variety include conglomerate, sandstone, siltstone, greywacke, mudstone and shale. *Quartzites* form when the clastic sediments composing such rocks recrystallize to varying degrees due to heat and/or pressure. Although therefore technically a metamorphic rock, quartzite is included in this material variety as it is defined here.

Roughly 3600 siliciclastic sedimentary rock artifacts make up between 6 and 7 percent of Harappa's lithic assemblage. Over 70% of these are grindingstones – querns, mullers, mortars or pestles, which are typically composed of sandstone/quartzite (Figure 4.2 D *left*). The potential geologic sources of those rocks and the acquisition networks through which they were brought to Harappa is examined in Chapter 5.

Multiple types of sandstone, quartzite, greywacke, siltstone and mudstone were used to create the artifacts comprising the remaining portion of this material sub-assemblage, which includes implements like whetstones and burnishers as well as a variety of non-utilitarian items such as beads, amulets, cubical weights, balls, "gaming" pieces and small ringstones or mace heads. Determining the geologic provenience of artifacts composed of such common but variable stone is difficult to do beyond the regional level at best. Whetstones (used for sharpening edged tools), for example, were typically made from compact fine-grained sandstones or siltstones (Figure 4.2 D *center*). Although such rocks occur in numerous regions surrounding the northern Indus Basin, the various sedimentary sequences of the Sulaiman Range (Shah 1991) – 225 km directly west of Harappa, would have been the source of the most abundant and best quality material for this type of artifact (*personal observation*).

Several hundred whole and fragmentary siliciclastic pebbles (4 to 64 mm in size) and cobbles (64 to 256 mm) of various descriptions (Figure 4.2 D *right*) have also been found at Harappa. These could have come from *almost* anywhere. Water-rounded stones of all sizes, textures and colors are found in many of the Miocene-Pliocene Siwalik and later Quaternary sedimentary formations that run along the entire western and northern margin of the Indus Basin (Cheema *et al*. 1977: 89-98) as well as in the beds of rivers draining the highlands surrounding the Punjab Plain (*personal observations*). Those rivers, however, could not have carried these stones very far out onto the plains. All pebbles or cobbles found at Harappa, no matter how small, had to have been intentionally transported several hundred kilometers to the site.

### Copper and copper minerals

The production of copper or copper alloy objects is the hallmark of *Chalcolithic* or Bronze Age societies in the Old World. For the purposes of this study, the material variety *copper* includes artifacts that are composed of processed copper metal as well as raw copper minerals. Throughout

this book I refer to processed metal objects (copper and otherwise) as being part of the Harappa's rock and mineral assemblage, although it is recognized that such artifacts are, technically, neither rocks nor minerals. Like heat-treated steatite, the original nature of material composing metal objects has been significantly altered. However, unless made from native metal, most were originally derived from a metalliferous rock or mineral and so are classified as such.

At Harappa, copper artifacts make up less than 5% of the site's rock and mineral assemblage. It might appear then that use of this material, although noteworthy, was somewhat limited – especially in relation to a much more abundant material like chert. However, unlike chert, metal objects and scraps that are no longer considered useful can be collected, recycled and re-used indefinitely. The copper artifacts at Harappa that escaped recycling and entered the archaeological record almost assuredly under-represent, to a significant degree, the amount of metal that actually was used at the site.

Although most copper artifacts at Harappa (Figure 4.2 E) are either identifiable copper alloy objects or non-descript fragments, a handful of raw copper ores have been found. Using XRD these have been identified (Appendix 4.2 D & E) as *chalcocite* (copper sulfide) and *malachite* (copper carbonate hydroxide). The potential sources and possible geologic provenience (s) of these ores are investigated in Chapter 12.

## MINOR ROCK AND MINERAL VARIETIES

Twelve materials make up most of the remaining 4.36% of Harappa's rock and mineral assemblage. These *minor* material varieties (Figure 4.4) are presented below in order of their decreasing overall abundance in the assemblage.

### Vesuvianite-Grossular

Chapter 9 is entirely devoted to examining the potential sources and probable geologic provenience(s) of vesuvianite-grossular garnet – a hard (6.5 to 7.5 on Mohs' scale), translucent, green-colored rock (Figure 4.4 A) that, after steatite and agate-jasper, was the third most common material used by Harappans to make beads and other small ornaments. Full details relating to that stone's appearance, mineralogy and other physical properties are presented in Chapter 9. Here, I briefly discuss how this material was identified and in what contexts it occurs at Harappa.

Vesuvianite and grossular garnet are two distinct minerals, which sometimes co-occur to form a massive gem-quality rock (Anderson 1966). To date, 543 objects and fragments composed of the co-occurring variety, which I simply call "vesuvianite-grossular," have been found at Harappa. Twenty-five of the fragments (roughly 5% of the material sub-assemblage) were directly identified using XRD. Appendix 4.2 F is a composite of four of those scans, which illustrates how the rock grades from pure grossular, to a vesuvianite-grossular mix, to pure vesuvianite, to a heavily weathered (chloritized) material with only traces of vesuvianite. One hundred eighty-two artifacts (nearly 30% of the material sub-assemblage) were classified based on specific gravity (SG) testing, which easily distinguishes dense vesuvianite-grossular ($\approx$ 3.0 to $\approx$ 3.5) from lighter minerals like quartz or serpentine (both $\approx$ 2.6).

The use of vesuvianite-grossular at Harappa was largely restricted in time and space. More than 90% of artifacts made of this stone are found on conjoined mounds E-ET. Most of the remaining ones were recovered from Harappan Period refuse areas away from the main habitation mounds (e.g., the "Low Western" Mound and the debris layers above the Cemetery area). Ninety-seven percent of the total number of vesuvianite-grossular artifacts from secure stratigraphic contexts (n = 180) come from Period

**Figure 4.4** Minor rock and mineral varieties at Harappa.



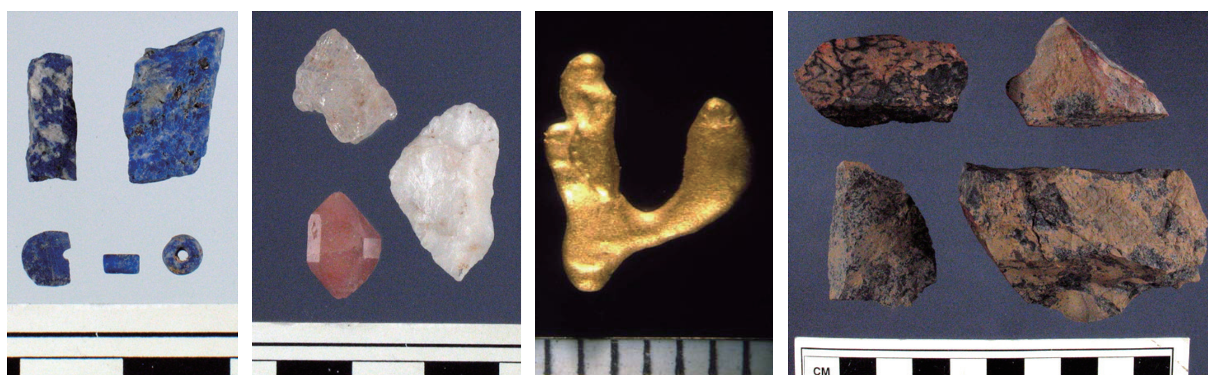

**A**. Vesuvianite-glossular

**B**. Igneous and metamorphic rocks (granite, schist, gabbro)




**C**. Gypsum – *alabaster* (left) and *selenite* (right)

**D**. Limestone

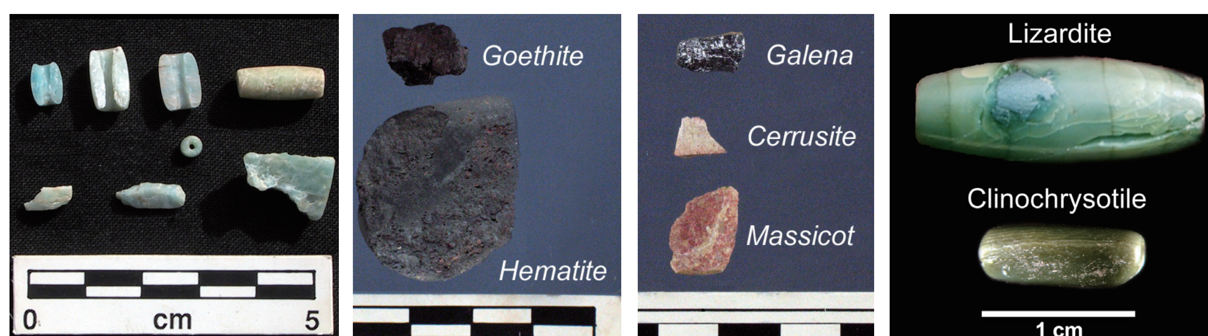



**E**. Lapis lazuli

**F**. Crystalline Quartz

**G**. Gold

**H**. "Ernestite"




**I**. Amazonite

**J**. "Ochre" minerals

**K**. Lead minerals

**L**. Serpentine

3C levels. Ninety-seven percent of those are from mounds E-ET but a few examples were excavated on mounds AB, F and the Mughal Sarai area. A single flake each was recovered in Period 1 and Period 5 levels on the north side of Mound AB.

### Igneous and Metamorphic rocks

A huge range of rocks are encompassed by the designations *igneous* (rocks formed from magma) and *metamorphic* (pre-existing igneous or sedimentary rocks altered by heat, pressure or chemically active fluids). Many of the "varieties" defined and described elsewhere in this chapter fall into these categories. For instance, steatite, quartzite and lapis lazuli are technically metamorphic rocks. However, for purposes of categorization, the materials that are classified as "igneous and metamorphic rocks" (Figure 4.4 B) here include a much more limited (albeit still very broad) range of material types than the two geologic terms normally encompass. The igneous variety at Harappa includes granite, andesite, rhyolite, gabbro and basalt. The metamorphic variety includes such rocks as gneiss, schist, phyllite and slate.

Altogether, 455 artifacts recovered at Harappa are of the "igneous and metamorphic rock" variety. Just over one-third (34%) of those are grindingstone artifacts such as querns or mullers (Figure 4.4 B *left*). These are discussed in greater detail in the chapter immediately following this one. Twenty-two percent are schist, phyllite or slate fragments, many of which are probably pieces from flat discs (palettes?) like the example (Figure 4.4 B *center*) in the Harappa Museum's reserve collection that comes from excavations carried out in the 1920s and 30s. Almost 15% are small non-diagnostic chunks and flakes of various igneous and metamorphic rock types that are probably debris from the manufacture of finished items. Many different types of finished it make up the remaining 30%. Gabbro was used to make cubical weights (Figure 4.4 B *right*), beads and small ringstones. There are basalt amulets, beads, large conical objects, hand mullers and several complete, apparently unmodified cobbles (Figure 4.5 A). The basalt cobbles may well have been "touchstones" (*kasoti* stones) like jewellers still used today for testing the purity of gold (Figure 4.5 B & C). Although some types of artifacts are found during certain periods only (for instance, truncated conical amulets made of basalt are found only in Period 3 levels), examples of igneous and metamorphic rocks have been recovered from all chronological phases and from all parts of the site.

Harappans could have obtained the igneous and metamorphic rocks they used from any one of the numerous geologic formations across northwestern South Asia in which they are found. Using EMPA, I conducted a small characterization/ provenience study of two basalt fragments from the site (Appendix 4.3). The results indicated that those particular artifacts probably were *not* related to the continental flood basalts known as the Deccan Traps, which lay far to the south of Harappa in peninsular India and Gujarat. Although I am in no way ruling out the possibility that other basalt objects or other kinds of igneous or metamorphic rock recovered at the site could have come from those regions, here I discuss only those sources located within or directly adjacent to the upper Indus Basin.

The closest occurrences of igneous and metamorphic rocks to Harappa are situated in the northern-most of the Kirana Hills outcrops (Alam *et al.* 1992), approximately 140 km directly north of the site, near the modern city of Sargodha. There, rhyolite, andesite, volcanic tuff, phyllite and slate are all found in the Precambrian Hachi Formation (ibid.). In Chapter 5, I demonstrate that during periods 1 and 2, residents of Harappa acquired most of the meta-sedimentary rocks they used for grindingstones from the Kirana Hills. It is, therefore, quite reasonable to assume that some of the igneous and metamorphic rocks found at the site during those periods also may have come from this region. Approximately 70 km

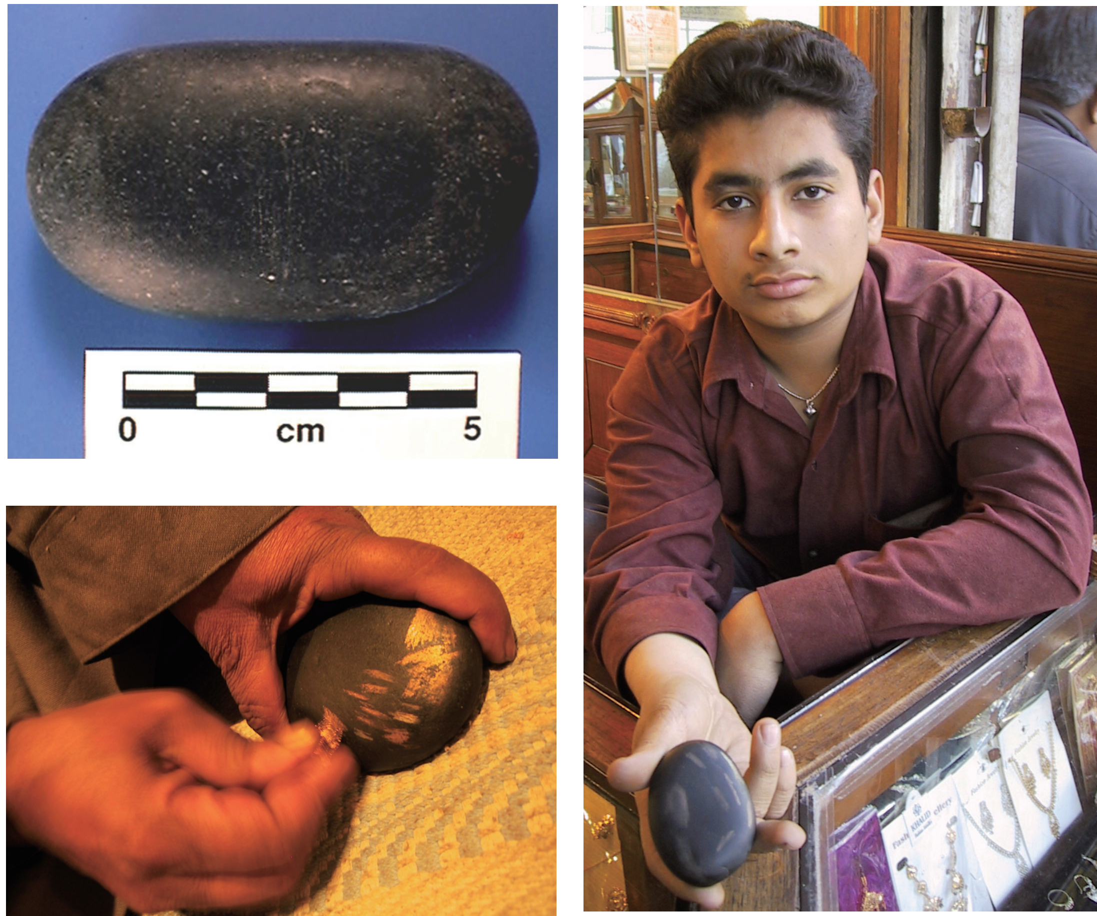



**Figure 4.5** Basalt "touchstones" or kasoti stones for testing gold purity.
Basalt cobble (H2000/2194-51) from Harappa excavations (top left). Jeweler in Lahore holding a basalt kasoti stone (right). Streaking a gold ornament across a kasoti stone to test its purity (bottom left).

beyond the Kirana Hills is the Salt Range, where granite can be found in the boulder beds of the Tobra Formation (Shah 1980: 12; *personal observations*) and an area of heavily weathered basaltic rock called the Khewra Trap exists (Jan and Faruqi 1995). Cobbles of different varieties of igneous and metamorphic rock can be found in the conglomerate beds of the Siwaliks (Brozovic and Burbank 2000), which ring the western and northern margins of the Indus Basin. Around 350 km southeast of Harappa, in the vicinity of Tosham in southern Haryana (Grover and Kumar 1980; Pareek 1986), a series of igneous outcrops break the alluvial plain that may have been important potential sources for rock of this kind. Several Early Harappan, Harappan and Late Harappan Period settlements lie in close proximity (≈ 25 km) to these outcrops including the site of Mitathal (Bhan 1969, 1975). Finally, basalt, gabbro, gneiss and other dark, magnesium and iron-rich (*mafic*) igneous and metamorphic rocks can be found in the ophiolite sequences that occur at various points along the northern and western margins of the Indus Basin. Residents of the Harappan and/or Early Harappan Period sites of the Bannu Basin, Gomal Plain or far northern Balochistan would have been in the positions to acquire these types of stone from the northern Zhob or the Waziristan ophiolites.

### Gypsum

The mineral *gypsum* (hydrated calcium sulfate) occurs in two forms – compact masses called *alabaster* and tabular crystals called *selenite*. Both forms have been recovered at Harappa (Figure 4.4 C) and

directly identified as gypsum using XRD (Appendix 4.2 G). In Chapter 10, the potential sources and probable provenience(s) of alabaster (the more common of the two forms) are examined in detail. Alabaster objects and/or debris fragments have been recovered in all major areas of the site and from every chronological phase and sub-phase from Period 1 through Period 3C.

## Limestone

Fewer than 300 artifacts made of limestone (a sedimentary rock consisting mainly of calcium carbonate) have been recovered at Harappa. It is somewhat surprising that rock of this type is not more represented in the site's assemblage given its widespread availability around the Greater Indus region. Also interesting is the fact that few artifacts made of this material are found in levels prior to Period 3C. During Period 3C, numerous distinct types of limestone were used residents of Harappa. The physical characteristics of the five most common types (Figure 4.4 D), their potential sources, probable geologic provenience(s) and questions relating to their use at the site are examined in Chapter 11. Three additional, less common, types of limestone are briefly discussed here.

### *Chalk*

Several fragments (one is from Period 3C levels on Mound F, the rest are surface finds turned in by workmen at Harappa) of the soft, pure white form of limestone known as *chalk* have been found at Harappa. Chalk deposits, although extensive in many parts of the world, are limited in South Asia. It is reported to exist in different parts of the Kashmir Valley (Bates 1873: 19). In Sindh, the only reported occurrences are in the upper part of the Laki Limestone formation around Thano Bula Khan in southern Sindh (Jafry and Ahmad 1991: 61). After that, one must travel southeast to Gujarat to find this type of limestone. Large chalk deposits are found in the Junagadh District (Desai and Pathole 1979) while smaller occurrences lie near Lakhpat in Kutch (Merh 1995: 168-169).

### *Variegated and fossiliferous limestone*

"Sang-i-Abri" (Cloud stone) is the colloquial term for a type of khaki to dark red *variegated limestone*. Just a few of artifacts (a bead and some blocks/slabs) made from this stone have been reported from Harappa (Vats 1940: 150, 177). "Sang-i-Miriam" (Stone of Mary) is a yellowish-brown to dark brown *fossiliferous limestone* that has long been used in South Asia both for decorative inlays (Figure 4.6 A) and for fashioning small ornaments. Only two artifacts have been found at Harappa made of this type of stone (Figure 4.6 B). The blocklet pictured on the right of the figure is from Period 3C levels in Trench 43, Mound F. Although the truncated conical amulet on the left is a surface find turned in by one of the workmen, it is clearly of Harappan design (amulets with the *exact* same form but made of different kinds of stone have been found in Period 3 levels).

Although fossiliferous limestones occur in many formations around the Indus region, those with the macroscopic characteristics of Sang-i-Miriam seem to be quite rare (*personal observations*). In the museum of the Geological Survey of Pakistan-Quetta there is a polished slab of Sang-i-Miriam said to be from Sangjani in the Rawalpindi District, Punjab. This would be the source nearest to Harappa. Sang-i-Miriam is also quarried today in the Jaisalmer District of Rajasthan near Habur (Figure 4.6 C). Further south, I have seen fragments and pockets of the stone near the Indus city of Dholavira on Khadir Island, in northern Kutch, Gujarat (Figure 4.6 D). Importantly, there are numerous finished objects and debris fragments made from Khadir Sang-i-Miriam in the collection of excavated stone from Dholavira (*personal observations* 2007-2008). The two artifacts from Harappa could have come from any one of these sources.




**Figure 4.6** Sang-i-Miriam (fossiliferous limestone)
[**A**] Inlay, Lahore Fort, Pakistan. [**B**] Truncated conical amulet and worked block, Harappa.
[**C**] Sang-i-Miriam at Habur, Jaisalmer District, Rajasthan. [**D**] Sang-i-Miriam at Khadir Island, Kutch, Gujarat.

### Lapis Lazuli

Most of the 174 lapis lazuli artifacts recovered during HARP operations are beads, unfinished beads and fragments of manufacturing debris (Figure 4.4 E). Examples have been found on every mound at the site and from all of its chronological phases and sub-phases (Appendix 4.4 *Figure 2*). Lapis lazuli is a rock that may contain varying amounts of several minerals including calcite, diopside and pyrite, but it is *lazurit*e (sodium calcium aluminum silicate sulfur sulfate) – a mineral isomorph of haüyne and sodalite – that provides the stone with its characteristic blue color (Leithner 1975; Hogarth and Griffen 1976a; Webster 1994: 263). Although other blue-colored minerals, such as azurite and sodalite, are sometimes mistaken for lapis lazuli, in most cases it is sufficiently distinctive so that an experienced individual may confidently identify it based on visual inspection alone. That is, if one has looked at enough genuine examples it is generally easy to spot (based on hue, luster, crystal habit and visible mineral associations) a different stone for which the blue color is probably not due to the presence of lazurite. Still, misidentifications can be made. Shaffer reported (1982: 193) that Walter Fairservis had analyzed "lapis lazuli" samples from several Indus Civilization sites including Mohenjo-daro and found them to actually be the mineral *azurite* – a hydrated copper carbonate with a brilliant blue color. So to be on the safe side a few of the more ambiguous-looking debris fragments from Harappa were analyzed using XRD (see Appendix 4.2 H for an example of one of those scans). The primary mineral phase in those samples was most definitely lazurite and I am quite confident that all other artifacts from the site that are classified as lapis lazuli are actually made from this stone.

In Appendix 4.4, I examine in detail the question of where the lapis lazuli used by residents of Harappan and other Indus Civilization peoples originated. As small study is conducted comparing the sulfur isotope ratios of archaeological lapis lazuli from Harappa and several other sites to geologic samples from multiple sources. Based on those results and given all other evidence that is presently available, I have come to the conclusion that the Sar-i-Sang area mines in the Badakhshan region of northern Afghanistan would have been the *only* viable sources of that stone. Lapis lazuli is therefore one of the few materials found at Harappa (the others being marine shell and the remains of oceanic species of fish) that provides unequivocal evidence for both the direction and extent of long-distance acquisition networks during the periods in which they are present.

### Crystalline quartz

Quartz (silicon dioxide) is the most abundant

substance in the earth's crust after feldspar (Deer *et al.* 1992: 469). Making a firm statement regarding the possible geologic proveniences of artifacts made from such a commonplace mineral is therefore problematic. It is possible to say that the crystalline varieties of quartz found at Harappa (Figure 4.4 F) usually (but not always) occur in association with igneous or metamorphic rocks (Pough 1988: 220-221). The 160 crystalline quartz artifacts recovered include beads or fragments of clear "rock crystal", "smoky" quartz, "milky" quartz, "rose" quartz and pink-colored bi-pyramidal crystals known as Mari "Diamonds." Nearly half (79 of 160) of these come from stratified contexts representing all periods and sub-periods from 2 through 3C. The majority (78%) of those that date to Period 3C and although they were recovered from each of the site's mounded areas as well as the cemetery area dump, the heaviest concentration (56% of the total for this period) were found in Trench 43 on Mound F.

The quartz crystals known as Mari "Diamonds" are highly distinctive and, because they were very likely derived from alabaster deposits in the Salt Range, they are discussed in the portion of this book (Chapter 10) featuring the alabaster provenience study. All or some of the remaining kinds of crystalline quartz at Harappa can be found (usually in granitic rock) in numerous parts of the Greater Indus region. Such areas where occurrences are found lying within or directly adjacent to the upper Indus Basin include the Kirana Hills (Heron and Crookshank 1954: 131; *personal observations*), the Northern Areas of Pakistan (Kazmi 1995b: 288), Himachal Pradesh (Geological Survey of India 1989a: 47), southern Haryana (Geological Survey of India 1989b: 34) and northern Rajasthan (Department of Mines and Geology 1989: 48-49; *personal observations*).

### Gold

Artifacts made of gold (mostly small beads and leaf or foil fragments) have been found on every major mound at Harappa. Approximately half of the 120 examples recovered come from securely dated strata spanning Period 1 through Period 3C. The other half are from surface or disturbed contexts and, therefore, it is possible that at least some of those were originally deposited in Late Harappan levels that were subsequently disturbed. The best evidence for gold-working at the site comes from Trench 54, where a gold droplet[1)] (Figure 4.4 G), small crucibles, a basalt touchstone (used in modern gold bazaars to test the purity of an item by observing the streak it leaves on the stone's black surface - see Figure 4.5) and an unusually heavy concentration of gold beads and fragments were found in deposits eroding from Period 3B and 3C levels (Meadow *et al.* 2001: 14-15).

The number of gold objects that have been found at Harappa and other Indus Civilization sites almost assuredly represents but the tiniest fraction of what was actually used. Any amount of the precious metal left over from the manufacture of finished items no doubt would have been scrupulously recovered and recycled, just as it is by modern goldsmiths in South Asia (or anywhere else for that matter). Also, in contrast to practices in other contemporaneous Old World civilizations, Harappans generally were not inclined to inter their dead with much in the way of wealth items (made of precious metals or otherwise). Although a few gold artifacts have been found in graves at Harappa (Dales and Kenoyer 1989a: 89, 91), most were apparently kept in circulation rather than permanently buried. Precisely how much was in circulation is difficult to estimate, but finds of jewelry hoards, such as those unearthed at Harappa (Vats 1940: 63-66) and Mohenjo-daro (Mackay 1931c: 522-524), suggest that the amount was probably substantial. Recently, the Archaeological Survey of India recovered ten kilograms of gold and silver ornaments from a hoard, which that had already been

1) this gold "droplet" may actually be a tiny placer nugget (J.M. Kenoyer *personal communication* 2001)

heavily looted, at the Late Harappan site of Mandi in western Uttar Pradesh (Sharma *et al*. 2000; Tewari 2004).

Where did Harappans obtain gold? There are many possibilities as it is a metal with a remarkably wide distribution across South Asia – a fact noted by Sir Edwin Pascoe when he discussed (1931: 674-675) the possible geologic sources for the gold artifacts found at Mohenjo-daro. Comprehensive and reasonably up-to-date accounts of the many occurrences, both major and minor, in Pakistan and India already exist (Ahmad 1969: 23-25; Nanda 1992; Radhakrishna and Curtis 1999; Shams 1995b: 240-243; Ziauddin and Narayanaswami 1974) and so only the most pertinent regions or occurrences are reviewed here. The Kolar gold fields of southern India have been the most productive in modern times (Wadia 1975: 444) and some scholars have proposed that Indus Civilization consumers may have obtained this precious metal through long-distance interaction with the Neolithic cultures of that region (Agrawal 1984: 165; Allchin and Allchin 1997: 102; Bhardwaj 1989: 327; Ratnagar 2004: 156; Rao 1985: 632-33). Although this is certainly a possibility that should not be dismissed, the goldsmiths of Harappa were in much closer proximity to other regional sources of that metal, three of which I discuss below.

A substantial portion of the gold produced in the modern world comes from *porphyry copper* deposits (copper mineralized in association with intrusive igneous rocks) that are rich in noble metals (Kesler 2004; Sillitoe 1979). The Khetri copper belt of northwestern Rajasthan is one of these deposits. Both gold and silver are recovered at the Hindustani Copper Ltd. smelting plants operating in this region today (Rao *et al*. 1997). If the Khetri belt was one of the major sources for the copper used by Indus Civilization peoples as has been proposed (Agrawala 1984), then some Harappan gold may have been derived from northwestern Rajasthan. Gold is also currently being recovered from porphyry copper deposits in the extreme western part of Balochistan around Saindak (Lamb 1988; Mining Magazine 2001; Shams 1995b: 241; Wolfe 1974). Ancient workings and smelting areas can be found throughout that region (Vredenburg 1901) and into eastern Iran (Bazin and Hübner 1969: 153-157). Immediately to the north, in the Gardan Reg region of southwestern Afghanistan, immense spreads of copper production debris were found in association with graves and ceramics dating to the third millennium BC (Dales and Flam 1969; Dales 1992; Fairservis 1961; Vredenburg 1901: 264-265). George Dales reported (1992: 26) that the analysis of a copper slag sample from Gardan Reg indicated that its "gold assay was very high, high enough to be commercially valuable."

The closest and most "obvious" sources from which residents of Harappa may have obtained gold, however, are the myriad rivers and streams that drain the mountain ranges north of the upper Indus Basin (Kenoyer and Miller 1999: 120). To this day, "gold-washers" work the placer deposits of the Indus and other rivers in the far north of Pakistan (Ahmad *et al*. 1975; Khan 1999; Tahirkheli 1960), the Soan (Gold) River and several of its tributaries on the Potwar Plateau (Heron and Crookshank 1954: 79), tributaries of the Jhelum river (Ahmad 1969: 25), the Beas River and other numerous other smaller streams in Himachal Pradesh (Director - Punjab Haryana and Himachal Pradesh Circle - Geological Survey of India 1971), the Sutlej drainage basin (Ruby 1998) and the Siwaliks at the base of the western Himalayas (Lal *et al*. 1985). Although occurrences there have been characterized as "meager" (Ahmad 1975: 176) and barely profitable for those working them in the modern era (Wadia 1975: 445), historical accounts from the Greek through the Mughal periods suggest that the mountainous regions and rivers of north of the Punjab were, in former times, major sources for gold (for discussions of the many literary references to gold from this region see Biwas 1996: 327-328; Nanda 1992; Peissel 1984; Ratnagar 2004: 156-157). I would

even submit that a phenomenon not unlike a "gold rush" could have taken place in this area during the later prehistoric period.

Gold rushes of eras past (Green 1993; Morrell 1941) all played out in the same basic way. Rich, previously unexploited deposits were discovered and all of the easy-to-recover metal was quickly consumed. After the initial "rush," gold became progressively more difficult to extract and the sources were abandoned or worked on a greatly reduced scale. The first gold artifacts in northwestern South Asia appear during the latter half of the fourth millennium BC in the Punjab, at Harappa and at Jalilpur (Mughal 1972b: 119). From this time forward, the precious metal is a constant feature in the archaeological and historical records of that region (Nanda 1992). It is therefore entirely possible that sources north the Punjab have been *continuously* exploited for more than 5000 years. The amount of gold recovered in the modern era is, in all likelihood, a pale reflection of what may have existed at the time sources there initially were worked. Consider the mid-19th century AD gold rush of northern California in the western United States. A survey of that region today would likely provide little indication of the incredibly rich alluvial deposits that once existed there and which, in a mere two decades, were largely exhausted (Clamage 1998). I am not necessarily suggesting that the deposits north of the Punjab were similarly rich or that a "rush" of the same scale or intensity as California's took place in northwestern South Asia during the Harappan Period, only that we should not evaluate the potential of this region as a gold source based on the amount of metal that is being recovered there today.

Admittedly, no material evidence has ever been found in regions north of the Punjab that would indicate that gold was being exploited there during the prehistoric period, nor is it ever likely to be. Ancient gold-washers would, quite obviously, have had little or no archaeological impact and it is highly unlikely that camps or settlements associated with such activities would be persevered in a dynamic mountainous environment like the Himalayas. The notion of a Harappan Period "gold rush" in this region is entirely hypothetical. It is, however, a hypothesis that eventually can be *tested*. There is every reason to expect that it might be possible to differentiate alluvial gold derived from sources in northwestern South Asia from that originating in the Precambrian rocks of South India, the gold-rich copper ores of Rajasthan or Balochistan, or from sources elsewhere. Geochemical comparison of Harappan gold artifacts with geologic samples collected from these regions is certain to be an important and productive area of inquiry in the future.

### "Ernestite"

"Ernestite" is the name given by Kenoyer and Vidale (1992) to an extremely fine-grained khaki-colored stone that is mottled with dark-brown to black patches and dendritic veins (Figure 4.4 H). It is a hard (Mohs hardness of at least 7), very tough (does not break or fracture easily) and fairly dense stone (SG ranging from ≈ 2.8 for the khaki-colored matrix to ≈ 3.2 for the brown-black portion). At Harappa and other Indus sites where it has been identified, such as Mohenjo-daro, Chanhu-daro and Dholavira, "Ernestite" was fashioned into small constricted cylindrical drills, which were used by beadmakers to perforate hard materials (namely microcrystalline silicates and vesuvianite-grossular). Using XRD and EMPA, Kenoyer and Vidale (1992) characterized it as an unknown variety of metamorphic rock composed of quartz, sillimanite-mullite and hematite-titanium oxide phases (ibid.: 506-507). Recently, however, I have conducted a series of follow-up analyses that instead suggest "Ernestite" is a type of *indurated tonstein flint* clay that has been deliberately heated to produce or enhance properties that made it a highly effective material for drilling hard stone beads. In Appendix 4.5, I provide full details on how I came to those conclusions and discuss the possible geologic

sources from which Harappans may have acquired the original raw material.

The utilization of "Ernestite" at Harappa was limited in space and time. All but a handful of the roughly 75 drills, drill rough-outs and debris fragments found to date come from the conjoined area of mounds E-ET. Most of those that do not were found in Harappan period dump debris or surface contexts away from the site's main habitation areas. Thirty-eight of the 40 "Ernestite" artifacts recovered from secure contexts came from Period 3C levels while the remaining two were from Period 3B strata. Interestingly, these temporal and spatial patterns seem to closely mirror those for vesuvianite-grossular – a rock that can have a Mohs hardness greater than 7 depending on its grossular content. It is probably no coincidence that stone of that variety is mostly found *when* and *where* beadmakers were also using "Ernestite" because "Ernestite" was the only material available from which drills capable of perforating it could be made (this association is discussed further in Chapter 9). Diamond was not available at this time and the microcrystalline silicate drill bits that Harappans used for other types of stone would have would have been wholly ineffective (explained in Appendix 4.5) on vesuvianite-grossular as well as the long style of carnelian beads. "Ernestite" drills represented a major technological innovation.

### Amazonite

The variety of the feldspar mineral *microcline* (potassium aluminum silicate) known as *amazonite* is easily recognized by its prominent cleavage face in combination with its characteristic white-green to blue-green appearance. Despite being one of the less abundant minerals at Harappa, examples have been recovered on each major habitation area at the site except Mound E and from every occupational phase except Period 3A. A selection of amazonite beads and manufacturing debris can be seen in Figure 4.4 I.

Amazonite, sometimes referred to in the literature as "green microcline," occurs in *pegmatites* (Deer *et al* 1992: 425-426). Pegmatites are zone of unusually coarse-grained igneous rocks that are important sources of rare elements and semi-precious minerals (including several in Harappa's assemblage). Early researchers speculated that amazonite artifacts from Mohenjo-daro may have come from a source in the Nilgiris Range of southern India (Pascoe 1931: 678; Mackay 1938: 500). However, this purported occurrence was long ago shown to probably not exist (Gordon 1935, 1936). Confirmed sources of gem-quality green microcline closer to the Indus region and Harappa include those found in the pegmatites of Pakistan's Northern Areas (Kazmi 1995b: 289). Perhaps the most likely source, however, lies in northern Gujarat. There, green microcline occurs in granite pegmatites southeast of Palanpur near the village of Derol (Foote 1898: 22) and amazonite pebbles originating from those rocks can be found in the bed of the adjacent Sabarmati River (ibid.: 29). On a loess terrace not far from this location, geologists R.B. Foote reported a prehistoric site where he recovered chert tools in association with amazonite fragments (Foote 1916: 142-143). Around 125 km southwest of this source area lays the Harappan site of Nagwada. Excavators there found chert drills and the abundant remains of amazonite beads in "different stages of manufacture" (Hegde *et al*. 1988: 58). Hundreds of amazonite debris fragments and beads in different stages of manufacture are present in the assemblage of excavated stone at Dholavira (*personal observations* 2007-2008).

### "Ochre" minerals

Several dozen examples of "ochre" minerals have been excavated at Harappa. The most common one is *hematite* – iron oxide (Figure 4.4 J). Appendix 4.2 K is a representative XRD scan of this mineral. A related hydrated iron oxide – *goethite* has also been positively identified (Appendix 4.2 L). Ochres such as these have a long history of use as mineral pigments in

South Asia (O.P. Agrawal 1999). Harappans certainly employed them when decorating ceramics (Dales and Kenoyer 1986a: 64) if not for other purposes.

Ochre minerals have been recovered from every mound at Harappa and from every one its occupational phases. Geologic occurrences exist across the Greater Indus region. Large and varied deposits of ochre are found in Jammu (Indian Bureau of Mines 2001: 27-29), the northern Punjab (Bender 1995b: 269), Balochistan (Ahmad 1975: 129), Sindh (Ahmad 1993: 18), western Rajasthan (Geological Survey of India 2001b: 88) and Gujarat (Merh 1995: 173). Residents of Harappa, however, would only have needed to travel 120 to 150 km north to find ample supplies. Red, yellow and green colored oxides of iron are found at numerous locations in the Kirana Hills and are mined today for use in the local paint industry (Butt *et al*. 1993: 8; Shah 1973: 10-11).

### Lead minerals

Over half of the 35 lead artifacts found at Harappa are in the form of raw, unadulterated lead ore. Ore fragments (Figure 4.4 K) composed of galena (lead sulfide), galena with stibnite (antimony sulfide), cerussite (lead carbonate) with anglesite (lead sulfate) and massicot (lead oxide) have been identified using XRD (Appendix 4.2 M, N, & O). A variety of lead objects, residues and slags make up the rest of this sub-assemblage. A small lead rod was found to be partially composed of *wulfenite* (lead molybdate) and graphite (for details on this artifact including its XRD scan see Figure 12.21 in Chapter 12). With the exception of a single galena fragment from Ravi Phase levels on Mound AB, all of the lead artifacts excavated from secure contexts date to periods 3B or 3C. In Chapter 12, I discuss potential lead sources and investigate the probable geologic provenience of these artifacts.

### Serpentine

The term *serpentine* refers to a group of hydrous magnesium silicate minerals (lizardite, antigorite and chrysotile) that form due to hydrothermal alteration of ultramafic rocks such as peridotites (Deer *et al*. 1992: 344-352). These minerals have highly variable macroscopic characteristics. They may be opaque or translucent, come in colors ranging from white to green to black and can have either a uniform appearance or one with a mottled or winding (hence the name) pseudomorphic texture (ibid.). For many years, most green-colored translucent varieties of stone encountered at Harappa were believed to be serpentine. However, when all stones classified as such were examined in early 2003 using specific gravity (SG) testing, it was discovered that most were too dense to be serpentine and so they were reclassified as vesuvianite-grossular (serpentines have a SG of approximately 2.6 while vesuvianite-grossular ranges from ≈ 3.0 to 3.5). Only around thirty finished objects or fragments of stone from Harappa are now thought to be serpentine. A selection of these may be seen in Figure 4.4 L. Several of the fragments were examined using XRD and found to be composed of either *lizardite* or *clinochrysotile* (see Appendix 4.2 P and 4.2 Q for a representative scan). Also using XRD, Vidale and Bianchetti (1997) had previously identified a lizardite bead at Mohenjo-daro.

Serpentine artifacts have been found on every mound at Harappa and from secure stratagraphic contexts representing periods 2, 3A, 3B and 3C. Stone of this variety occurs at many locations around the Greater Indus region, especially in the ultramafic ophiolite sequences found along its northern and western margins (Asrarullah *et al*. 1979; Kazmi 1995b: 286). Bead and amulets composed of serpentine varieties that closely resemble those found at Harappa are made today at the shrine of Shah Biwal Noorani in the southern Las Bela district of southern Balochistan (*personal observation*). The craftsmen working there confirmed that those varieties come from occurrences in the nearby ultramafic rocks of the Las Bela ophiolite. Identical looking serpentine minerals are

found closer to Harappa itself in ophiolite sequences located in the Zhob district of Balochistan, North Waziristan, the Dargai area of the NWFP and the Gilgit-Skardu region of the Pakistan's Northern Areas (Awan 1987; Kazmi 1995b: 286; *personal observations*). Serpentine occurrences in central Rajasthan (Sen Gupta 1937) should also be considered as potential sources.

## MISCELLANEOUS ROCK AND MINERAL VARIETIES

Rock and mineral types for which ten or fewer examples have been recovered at Harappa are termed *miscellaneous* varieties (Figure 4.7). Although collectively these artifacts make up a mere 0.12% of the assemblage, they are as important as any of the more abundant materials in it because of the information they provide on the scope and diversity of Harappa's rock and mineral acquisition networks. The miscellaneous varieties are presented below in alphabetical order.

### Almandine garnet

*Almandine* (iron aluminum silicate) is a dense (SG ≈ 4.3), dark red variety of garnet that occurs in thermally metamorphosed pelitic rocks (Deer *et al*. 1992: 31-46). A single battered fragment of an almandine garnet crystal (Figure 4.7 A) was found in Period 1 levels on the northern side of Mound AB. Another example came from disturbed sub-surface levels on Mound E. Using specific gravity testing, these artifacts were easily distinguished from similar looking but less dense (SG ≈ 3.6) pyrope garnet.

The garnets from Harappa might have come from any of several locations. Almandine is but one of the many varieties mined in garnet-rich Rajasthan today (Kanranth 2000: 200; Sethi 1966: 34-36). To the north of Harappa, gem quality almandine garnet is found in the Neelum Valley of Kashmir (Jan *et al*. 1995) and in various parts of the NWFP and Northern Areas of Pakistan (Kazmi 1995b: 289).

Almandine garnet is a hard stone (Mohs 7.25 to 7.5). Drilling this stone would have been impossible or at least very difficult with the tools Harappans possessed (although small beads could be made by "pecking" or chipping a hole through them). The Ravi Phase fragment could definitely not have been perforated using the chert and jasper (Mohs ≈ 7) tools available at that time. Even "ernestite" drills may have been largely ineffective. Blanche Barthélémy de Saizieu suggested (2003: 29) that hardness was the reason why garnet was infrequently used to make beads at the Neolithic site of Mehrgarh, in Balochistan. This may also account for why so little of this material is found at Harappa.

### Calcite

Artifacts made of *calcite* (calcium carbonate) are rare at Harappa. The few calcite crystals (easily distinguished from naturally occurring pedogenic calcium carbonate nodules) that have been identified (Appendix 4.2 R) could have come from any of the geologic formations surrounding the Upper Indus Basin. In 1990 a small, complete stone ring (Figure 4.7 B) was found by one of the local workmen at Harappa while walking across the site. It appears to be composed of *travertine*, or onyx marble (a form of calcite) and looks remarkably like the ornamental stone that is quarried on a large scale today in the Chagai Hills of Balochistan (Ahmad 1975: 124-128).

### Fluorite

A light aqua-green-colored stone fragment was found in Period 3C levels of Trench 11 on Mound E while a similar looking material within a matrix of milky white crystalline stone (Figure 4.7 C) was recovered in disturbed strata nearby. The XRD results (Appendix 4.2 S) indicated that both were examples of *fluorite* (calcium fluoride) – a mineral with a history of use both as a flux for lowering the melting




**Figure 4.7** Miscellaneous rock and mineral varieties at Harappa.

point of metals (its name derives from the Latin word *fluo* – "to flow") and as an ornamental stone (Deer et a. 1992: 673; Rapp 2002: 114). A broken aqua green colored bead found on the site's surface by one of the workmen had a specific gravity of 3.1 – exactly that of fluorite.

Fluorite is an extremely variable mineral both in terms of its appearance and the types of geologic environments that it forms in (Deer et a. 1992: 672-675). The artifacts from Harappa might have come from any number of regions except, importantly, some of those closest to it. No occurrences have been reported from the Salt Range, Sulaiman Range or Kirana Hills regions. Fluorite can be found in areas farther north of Harappa such as Dir and Hazara in the NWFP (Ahmad 1969: 81, Kazmi 1995b: 289), Ladakh (Waza *et al.* 1977) and Himachal Pradesh (Rawat 1983). To the west-southwest of Harappa in Balochistan, there are "trivial showings" in the northern Zhob District (Kazmi and Jan 1997: 468) while a rich cluster of occurrences is found in the northern Koh-i-Maran Range in the Kalat District (Mohsin and Sarwar 1980). Far to the south, the Amba Dongar fluorite deposit of eastern Gujarat is the largest in the Subcontinent (Balasubramaniam and Vekaria 1980). Finally, occurrences of this

mineral are reported in various districts along the length of the Aravalli Range of Rajasthan (Geological Survey of India 2001b: 61-63).

### Fossils

Several fossils have been found at Harappa including two large disc-shaped foraminiferans known as *nummulites*. The nummulite on the right hand side of Figure 4.7 D was found in the Period 3C Harappan dump debris that associated with the cemetery area. The one on the left side was found in Period 4 levels on Mound AB. Fossils of this type can be found in Eocene formations of both the Sulaiman and Salt Ranges (Ashrafuddin and Farooqui 2002; *personal observations*).

### Kaolinite claystone

A tiny reddish-colored bead (Figure 4.7 E) was discovered in a small pot buried within a Late Harappa Phase (Period 5) house floor on the north side of Mound AB. Non-destructive XRD and VP-SEM analyses (detailed in Appendix 4.6) found it to be primarily composed of *kaolinite* (aluminum silicate hydroxide) with a minor phase of hematite. The raw material is probably best described as a hematitic kaolinite claystone or clayrock. Such stone is not particularly uncommon and is often, though not exclusively, found in association with coal or iron deposits (Loughnan 1978). The rock from which the bead was made could have come from many different regions. In the Hazara District of the NWFP "hematitic claystone layers " have been reported (Klinger *et al* 1963: 101). Further south, claystone beds and clasts, some of which are red, are also present in the Warcha Formation of the Salt Range (Ghazi and Mountney 2009).

### Mica

Small sheets of mica (Figure 4.7 F) have been found in Period 3C levels and surface deposits on Mound E, Period 3C levels beneath the Mughal Sarai south of Mound E and in the Period 3C dump debris associated with the cemetery area. These were possibly related to gold-smithing or may have been used for medicinal purposes (Kenoyer 2006 *personal communication*). X-ray diffraction analysis indicates (Appendix 4.2 T) that these artifacts are of the mica variety *muscovite* (potassium aluminum silicate hydroxide fluoride). This mineral occurs in a wide range of metamorphic environments but is most common in granite pegmatites (Deer *et al* 1992: 292-293). Muscovite bearing pegmatites are found west and north of Harappa in Himachal Pradesh (Director – Punjab, Haryana and Himachal Pradesh Circle – Geological Survey of India 1971: 32), Kashmir (Ahmad 1981: 23) and the Peshawar and Hazara Divisions of the NWFP (Bender 1995b: 269). Of the many mica deposits found throughout Rajasthan (Geological Survey of India 2001b: 86-87), those in the northern Aravallis (Geological Survey of India 1989b: 32) would have been most accessible to Harappan peoples living on the plains of the upper Indus Basin.

### Nephrite jade

A semi-translucent, spinach-green colored truncated conical amulet (H88/182-14) with a high-polish (Figure 4.7 G) was recovered in a cemetery area debris layer above a burial pit dated to Period 3B. Non-destructive XRD and VP-SEM analysis (Appendix 4.7) revealed that this object is composed of *nephrite*. Nephrite is a metamorphic rock (a calcium magnesium iron silicate hydeoxide in the tremolite-actinolite series) that, along with the metamorphic mineral *jadeite* (sodium aluminium iron silicate), is, by widely accepted convention, one of the mineralogically genuine varieties of *jade* (Twilley 1992). The presence of nephrite jade at Harappa *could* mean that some form of long-distance trade existed with the well-known nephrite source area along the Karakash River near Khotan (Hetain) in the western Chinese province of Xinjiang (Tosi 1977). However,

there are closer occurrences of this stone. Using XRD, Oxford University geologist B.C.M. Butler confirmed (Butler 1963a, 1963b) that cobbles he collected in the Teri Toi River of Kohat, NWFP were nephrite. One of the cobbles he described would seem to be visually and mineralogically identical to the Harappan amulet (see Appendix 4.7 for full details).

#### Prehnite

Fragments of *prehnite* – a pale green mineral with a vitreous luster (Figure 4.7 H), have been recovered from Period 3C levels on Mound ET and directly identified using XRD (Appendix 4.2 U). Prehnite (calcium aluminum silicate hydroxide) most commonly forms either as a secondary hydrothermal mineral within cavities in basaltic rocks or as a primary mineral in contact metamorphosed impure limestones (Deer *et al*. 1991: 386). Those occurrences found in the Deccan Traps are examples of the former mode of formation (Wise and Moller 1990). In the latter instance, it may be found in association with vesuvianite-grossular - as it is in the ophiolite sequence near Muslimbaugh (formerly Hindubaugh) in the Zhob District, Balochistan (Bilgrami and Howie 1960). Prehnite has also been reported in or near other South Asian ophiolite sequences including those of Las Bela (Vredenburg 1904) and Waziristan (Badshah *et al*. 1997).

#### Sulfur

A small bright yellow stone fragment (Figure 4.7 I) recovered from a disturbed context on Mound ET was identified using XRD as pure *sulfur* (Appendix 4.2 V). The nearest occurrences of this mineral to Harappa, although very minor in size, would have been in the Salt Range, beginning 225 km north of the site (*personal observations*). Substantially larger sulfur deposits are found in Balochistan at Sanni in the Kalat District and Koh-i-Sultan in the Chagai Hills (Ahmad 1963).

#### Tourmaline

A fragment of green *tourmaline* – identifiable by its hexagonal structure, vertically striated exterior and glassy fracture (Figure 4.7 J) – was found in disturbed strata within Trench 53, located between mounds AB and E. Minerals in the tourmaline group typically occur in granite pegmatites and can be found in colors ranging from opaque black to blue, green, red or clear (Deer *et al*. 1992: 130-137). Although tourmaline occurs widely across Rajasthan (Rajasthan Mineral Bulletin 1997a: 14), green varieties have not been reported. Gem-quality tourmalines of that color can be found at several localities in Pakistan's Northern Areas, as well as the Neelum Valley and Padar area of Kashmir (Jan *et al*. 1995; Kazmi and Jan 1997: 476; Mehta 1957: 62; Wadia 1975: 459).

#### Turquoise

Turquoise artifacts are found at Harappa in the form of beads and unworked fragments. One of the beads was recovered within a coffin burial dated to Period 3B and two fragments came from Period 3C levels. The remaining half dozen artifacts are from disturbed strata that were very likely derived from Period 3C or later levels. Despite being few in number, turquoise artifacts have been found on each major mound at the site.

*Turquoise* (hydrated copper aluminum phosphate) typically forms in arid environments as water peculates down through aluminum-rich rocks in the presence of copper (King 2002: 113). The color of this mineral can range from sky blue to apple green and it often patterned with patches or web-like seams of darker materials. There are several rocks and minerals, such as *azurite*, *lazulite*, *variscite*, *chrysocolla* and copper-stained chalcedony, which may resemble turquoise to the extent that they are mistaken for it or intentionally used as simulants for lapidary purposes (King 2002: 112; Pogue 1915: 131-133). Using XRD, two fragments from Harappa (Figure 4.7 K) were directly identified as true (mineralogically genuine)

turquoise (see Appendix 4.2 W for a representative scan).

The existence of true turquoise deposits in South Asia has long been doubted (Bauer 1904: 397; Laufer 1913: 1-5). Occurrences reported in west-central Rajasthan near Ajmer and Ramgarh are now thought to "blue copper ore" or *azurite* – a hydrated copper carbonate (Iyer 1961: 72-73). More recently Jean-François Jarrige and Usman Hassan (1989: 160) reported the existence of old turquoise mining pits near Dalbandin in the Chagai Hills of western Balochistan. A sample of a blue-green turquoise-like material personally collected from that location by Jarrige was provided for this study and analyzed using XRD. The results of that scan (Appendix 4.2 X) indicate that the material is *not* turquoise but, rather, a stone composed mainly of quartz with a secondary phase(s) that suggests copper staining. The quartz content of this sample was further confirmed by placing a piece of it in hydrochloric acid. Turquoise will dissolve in acid (Pough 1989: 209) and the silica-rich Chagai sample did not. Chrysocolla (a hydrated copper silicate with a bright blue-green color) can become impregnated with silica and "may be confused with turquoise" (Poque 1915: 132). Jarrige's sample is, therefore, probably best characterized as "agatized" chrysocolla. E.W. Vredenburg encountered "turquoise blue" chrysocolla of this kind at multiple locations during his geologic survey of the western Balochistan region (Vredenburg 1901: 291-293). The Chagai Hills are certainly the type of geologic environment where turquoise *could* form and there are other mentions of the stone's occurrence there (e.g., Kazmi 1995b: 289). However, no conclusive studies have yet been published and so it is not considered as a potential source area at this time.

Turquoise then is the only rock and mineral variety in Harappa's assemblage other than lapis lazuli that, apparently, cannot be found in South Asia proper (considered here to be the area encompassed by modern India and Pakistan). This makes it an excellent indicator of the extent of long-distance trade networks external to the Greater Indus region. It is unlikely that Harappan turquoise trade networks extended all the way to deposits in Egypt (Hussein *et al.* 1995) or central China (Qi *et al.* 1998; Qian and Xu 1993) simply because there were much closer sources of that material. Perhaps the best known of these are the famous mines at Nishapur and Damghan in northeastern Iran (Khorassani and Abedini 1976; Manutchehr-Danai 1977). Maurizio Tosi (1974b), however, suggests that those sources may not have been exploited during the third millennium BC and instead points to deposits in Uzbekistan's Kyzyl Kum desert (Klyavin 1974) that were clearly being worked at that time as the likely source of the many turquoise artifacts found at Helmand Tradition sites of Shahr-i-Sokhta and Mundigak (Bulgarelli 1981; Jarrige and Tosi 1981). Material from the Kyzyl Kum deposits and perhaps other Central Asian sources like the one in the Akturpak region near the Ferghana Valley (Turesebekov and Meshchaninov 1983), could have entered Indus trade networks indirectly via Harappan interaction with the turquoise-using Helmand Tradition cultures. On the other hand, turquoise artifacts are found at the Harappan site of Shortughaï in northern Afghanistan (Francfort 1989: 145). At least some material from Central Asian sources may have entered Indus acquisition networks via that region. Lastly, the turquoise deposits of Tibet (Pogue 1915: 42) must be considered as potential sources. Occurrences in the western part of that region are the closest ones to Harappa and there is clear evidence that connections existed between cultures of the northern Subcontinent and those of the Tibetan Plateau and beyond during the third millennium BC (Fairservis 1975: 312-218; Stacul 1992, 1994; Xu 1991).

## MATERIAL VARIETIES AT HARAPPA KNOWN ONLY FROM PREVIOUS EXCAVATIONS

Several materials were found during earlier excavations at Harappa that have not been encountered again in the over two decades of work there by the HARP. For this reason, they were not considered when calculating the proportions of the different varieties making up the site's rock and mineral assemblage. Relatively few examples of these materials are recorded in Vats' 1940 site report and so, more than likely, they would have fallen into the miscellaneous category. It is, nevertheless, important to discuss them here in order to fully illustrate the range of rocks and minerals in use at Harappa and to thoroughly assess the extent and possible directions of acquisition routes.

### Silver

No artifacts made entirely of silver have, as of yet, been recovered during HARP operations, although gold sheeting wrapped around what may be a silver wire has been found as well as a small lump in which gold and silver have been cold hammered together. A small number of artifacts from mounds AB and F made entirely of silver (a vase, a broach, a bangle, two bosses and various beads) are recorded in Vats' 1940 excavation report. The apparent scarceness of this precious metal at Harappa, rather than being indicative of its limited of use there, may largely be due to factors relating to its preservation (or rather lack of) in the saline, moisture-laden soil of the site. Silver, in contrast to gold, is oxidizable and much more water-soluble (Guilbert and Park 1986: 744). Under certain burial conditions it is subject to "complete disintegration through severe internal corrosion and embrittlement" (Drayman-Weisser 1992: 192). Thus, many of the objects made of this material that escaped recycling four millennia ago at Harappa may have since degraded to the point that little or no trace has been left behind (especially small ornaments and tiny fragments). Still, we have been able to glean from the discovery of jewelry hoards and individual finds at numerous other settlements, both large and small, across the Greater Indus region that silver was an important and widely traded metal during the Harappan Period (for details on these see Ratnagar 2004: 197 or Lahiri 1992). In Chapter 12, I present the results of compositional and geologic provenience studies of silver artifacts from several of those other sites. Here, I make a few remarks regarding how Harappans may have acquired this metal and from where.

Silver in its native state is quite rare, much more so than native gold (Dana 1957: 404). For this reason, it is thought that the majority of this metal used throughout history was won by the *cupellation* (refinement through the oxidation of base metals) of *argentiferous* (silver-rich) lead ores (Rapp 2002: 147). A number of scholars have suggested that Harappan silver probably was derived in that way (Asthana 1993: 276; Biwas 1996: 329; Mackay 1931c: 524; Ratnagar 2004: 193; Sana Ullah in Mackay 1938: 599). A lead ore body may be considered viably argentiferous if it contains more than ten parts per million (10 ppm) silver (Craddock 1995: 211). Such deposits are found at multiple locations across northwestern South Asia (I discuss these, along with the other lead deposits of the Greater Indus region, in Chapter 12). In addition, small amounts of lead were detected in analyses of silver artifacts from Mohenjo-daro (Hamid, Sana Ullah in Mackay 1938: 478, 599) and Lothal (Lal 1985: 656), which *might* indicate that the metal used to make those objects was derived from a lead ore rather than native silver.

It is worth pointing out that ores such as chalcopyrite and chalcocite can also be argentiferous (Craddock 1995: 232; Dana 1941: 402; Gregg 1934) and, therefore, the possibility exists that at least some of the silver found at Indus Civilization sites may have been a byproduct of copper production. In

fact, in the analyses of silver artifacts from Mohenjo-daro and Lothal cited above, copper was detected in much greater amounts (from 2.67% up to 7.87%) than was lead (from 0.42% to 1.64%). Copper (and for that matter lead) could have been deliberately added during the manufacture of those objects (Bhardwaj 1989: 327), but this is by no means certain. What is certain is that Harappans were heavy consumers of copper and that silver is currently being recovered from argentiferous copper deposits in two regions that may have been exploited in the late-prehistoric era – the Khetri copper belt of northern Rajasthan (Rao *et al*. 1997) and the Saindak copper prospect of western Balochistan (Mining Magazine 2001; Wolf 1974).

### Arsenical minerals: Löllingite and Orpiment

Two arsenical minerals were recovered from Harappan Period levels on Mound F during excavations in the 1920s. A "black lump" found in Vats' Trench I was identified by Sana Ullah (in Vats 1940: 90) as *löllingite* (iron arsenide). Specimens of this material were also recovered at Mohenjo-daro (Pascoe 1931: 684-685, 690). Löllingite is a relatively uncommon mineral that can form both in sulphide deposits and pegmatites. Occurrences of the latter type are reported in association with gem-quality tourmalines in the Stak Valley of Pakistan's Northern Areas (Laurs *et al*. 1998) and in the gold-bearing Dhawar schists of the Gulbarga District, Karnataka (Mahadevan and Krishna Murthy 1945). In the Banswara District of southeast Rajasthan, native gold occurs with löllingite and arsenopyrite at Bhukia (Golani *et al*. 1999).

In Vats' Trench V, a small lump of *orpiment*, or arsenic sulphide, was recovered (Vats 1940: 468). This substance may have been used to alloy copper (although Kenoyer and Miller 1999 consider this unlikely), as a yellow pigment (O.P. Agrawal 1999: 191) or even for medicinal purposes (Treleaven *et al*. 1993; Watt 1885: 321). Orpiment, like löllingite, is not a common mineral. In Pakistan, it is mined in Chitral and small amounts are found at a few other locations in the north of the country (Ahmad 1969: 4-5; Shams 1995b: 255). "Minor occurrences" and "scattered fragments" are reported in the Zanskar and Kumaon regions of the Himalayas (Chatterjee 1963a: 12; Krishnaswamy 1979: 55).

### Fuller's Earth

During the 1924-25 excavation season at Harappa, a wide (≈ 3.5 m) but shallow (≈ 55 cm) depression was encountered among a group of houses in the central part of Mound AB (Vats 1940: 154). Lining the depression was a "filmy coating of bluish green earth with a soft, soapy feel," which was later identified by Sana Ullah (ibid.) as *Fuller's Earth* or, as it is known in this part of South Asia, *Multani Mitti* (Multan Earth). Fuller's Earth is a type of highly absorbent calcium montmorillonite clay that has been used throughout history as a substance for cleaning textiles (Robertson 1986). The designation "Fuller" refers not to a person but to an occupation – one who scours, or *fulls*, cloth to make it clean (Aronson 1996). Evidence that suggests some sort of washing activity may have taken place at the location at Harappa where this soapy material was found. The depression, or "reservoir" as it is noted on the trench plan (Vats 1940: Plate XXXII), which the Fuller's Earth was lining is situated in an area, perhaps a courtyard, where water was clearly being used and controlled – there are brick-on-edge platforms nearby, a water chute and several drains including a long one that would have carried waste water away from the area.

Sana Ullah inferred "that this earth was imported" (in Vats 1940: 154) and he was certainly correct as there would have been no local sources for this variety of clay. The most extensive deposits of Fuller's Earth in northwestern South Asia occur in Sindh, especially in the Lakhi Range and the Rohri Hills area between Sukkur and Kot Diji (Ahmad 1969: 67; Shah 1977: 115). Numerous occurrences may

also be found throughout the west and northwestern portions of Rajasthan (Department of Mines and Geology 1989: 81-82; Pareek 1984: 71). The deposits nearest to Harappa, however, are found just over 200 km directly west of the site in the Rakhi Nala and Taunsa areas of the Sulaiman Range piedmont (Hassan *et al*. 1995: 31-32; Shah 1977: 115; Yusaf *et al*. 1989).

## SPATIAL AND TEMPORAL ASPECTS OF HARAPPA'S ROCK AND MINERAL ASSEMBLAGE

Now that Harappa's rock and mineral assemblage has been presented in all of its diversity, it is possible to take a step back and examine it on a broad-scale, as a single entity, composed of many different and potentially variable "elements." These "elements" are the major, minor and miscellaneous rock and mineral varieties that have been defined and described in this chapter. In this section, I am mainly concerned with which of them are present or absent in a particular chronological phase and/or on one of the major habitation areas at the site. Much more detailed examinations of select varieties take place in the eight chapters that follow this one. The purpose here is to determine if the suite of rocks and minerals acquired and used by Harappans, *as a whole*, varied from period to period and from mound to mound. If it did, then how does that inform the three lines of inquiry that were outlined in Chapter 1? Before addressing those questions, however, it is necessary to consider the following issue: To what degree is any evident variation in the composition of the rock and mineral assemblage a reflection of the actual behaviors of Harappans living in different periods and/or parts of the site, as opposed to being due to other factors, such as the physical constraints of the site and the research strategies of the excavators? In order to evaluate this, it had to be taken into account how the assemblage, as a set of deliberately recovered archaeological remains, was distributed across space and time at Harappa. The first task was to determine the spatial and temporal contexts of the artifacts making up Harappa's rock and mineral assemblage.

### Contextualizing the rock and mineral assemblage

In order to determine the spatial and temporal contexts of the artifacts making up Harappa's rock and mineral assemblage, a list of every excavation/survey unit (known as a "lot") that contained one or more stone or metal objects was first compiled using the tabulation database. Excavation field books and stratigraphic section drawings were then consulted. Those lots associated with stratigraphic contexts that were not secure (surface, sub-surface rubble, the fill inside of brick-robber trenches, root holes, animal burrows, etc.) were flagged. The remaining ones were synchronized with unpublished lists of lot chronological associations already worked out by Drs. J. Mark Kenoyer and Richard Meadow for certain phases and areas of the site. Using the field books and section drawings, Dr. Kenoyer and I went then through the entire list again, lot by lot, to confirm associations. The stratigraphy of Harappa is highly complex and contextual data in the tables below should be considered provisional until a final version is published by the HARP directors.

### The spatial and temporal distribution of the rock and mineral assemblage

The physical locations where rock and mineral artifacts are found at Harappa reflect the behaviors of its prehistoric inhabitants as well as various other site formation processes (some cultural, some not) that have acted upon them. The way in which the assemblage that is available for study is spatially and temporally distributed, however, is a function of both the physical aspects of the site as well as the strategies of the researchers who recovered the artifacts. For

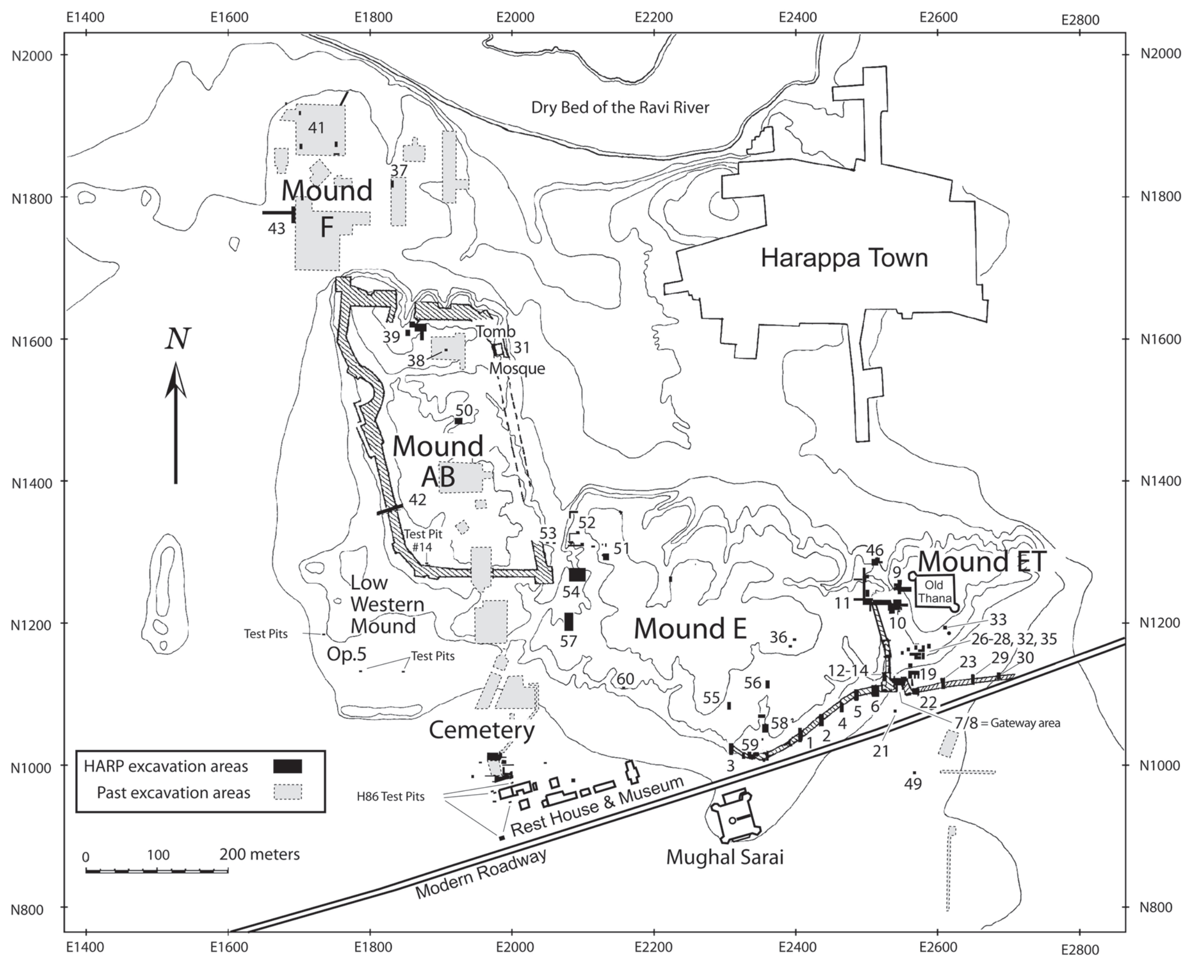



**Figure 4.8** Harappa site plan with numbered trenches and excavation areas where rock or mineral artifacts have been recovered.

various reasons, some time periods and areas at Harappa are better represented in the assemblage than others. It is vitally important to be mindful of this when comparing sub-assemblages from different parts of the site and from different phases.

On the preceding page is the site plan of Harappa (Figure 4.8). Marked in black and labeled by trench, operation (Op.) or test pit (TP) number are the HARP excavation areas in which rock and mineral artifacts have been recovered. This basically includes all but a handful of the trenches (mostly small test pits) that have been placed at the site by the HARP. The areas of Harappa excavated by past researchers are marked with gray shapes. Figure 4.9 is a table showing how the rock and mineral assemblage recovered during HARP operations is distributed among the major areas of the site. Since the project commenced in 1986, much of the research emphasis has focused on those parts of Harappa that had not been examined during previous excavation projects – namely, mounds E and ET. Nearly every season has seen large-scale excavations conducted in those areas. Although test pits, small trenches and surveys were made in all parts of the site during the early years of the project, it was not until the mid-1990s that large-scale excavations began on Mound AB and not until the later-1990s that they started on Mound F. As a consequence, most of the rock and mineral artifacts recovered over the past two decades – fully two-thirds of the site's entire assemblage, comes from the conjoined area of mounds E and ET. Mounds AB and F together comprise roughly half of Harappa's main habitation area but are represented by only around one-quarter of the total assemblage.

**Figure 4.9** Distribution of Harappa's rock and mineral artifact assemblage among the major areas of the site (based on all 56,350 artifacts).

| *location* | *percentage* |
| --- | --- |
| Mound AB | 19.54% |
| Mound E | 40.14% |
| Mound ET | 26.51% |
| Mound F | 6.73% |
| Mughal Sarai | 0.31% |
| Other* (cemetery, dumps, misc. finds, off-mound survey) | 6.76% |

**Figure 4.10** Distribution of the rock and mineral assemblage through each chronological phase and by excavation areas. Percentages based upon number of artifacts from secure contexts (total n = 32,365) and number of excavation lots containing stone artifacts (total n = 3024). Excavation areas list by Trench number or abbreviation (C = Cemetery, S = Sarai, TP = test pit).

| | *by artifact* | *by lot* | *Trench / excavation area* |
| --- | --- | --- | --- |
| **Period 1** | 11.59% | 5.39% | 39 |
| **Period 2** | 7.95% | 9.33% | 1, 2, 11, 39, 42, 52, 58 |
| **Period 3A** | 6.10% | 4.66% | 1, 2, 10, 11, 21, 39, 42, 52, 54, 58, 59, C |
| **Period 3B** | 10.88% | 19.84% | 1, 9, 10, 11, 21, 22, 37, 39, 42, 49, 52, 54, 56, 57, 58, C, TP-14 |
| **Period 3C** | 62.81% | 59.95% | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 19, 21, 22, 23, 27, 28, 31, 32, 33, 35, 36, 37, 39, 41, 42, 43, 46, 50, 51, 52, 54, 55, 56, 58, 59, 60, C, S, TP-H86, TP-Op.5 |
| **Period 4** | 0.17% | 0.40% | 38, 43 |
| **Period 5** | 0.49% | 0.43% | 38 |

Figure 4.10 is a table showing how Harappa's rock and mineral assemblage is distributed among site's the periods and sub-periods. Distribution was calculated in two different ways: 1) Of the over 56,000 artifacts making up the rock and mineral assemblage, exactly 32,365 are from chronologically secure contexts. The percentages in the second column of the figure were calculated based on the total number of stone artifacts from secure contexts that are found in each period. 2) Of the approximately 10,000 excavation

**Figure 4.11** Temporal and spatial distribution of Harappa's rock and mineral assemblage. Percentages calculated by the number of artifacts recovered from secure contexts in walled mounds only (cemetery/off-mound artifacts excluded).

| | *Period 1* | *Period 2* | *Period 3A* | *Period 3B* | *Period 3C* | *Period 4* | *Period 5* |
|---|---|---|---|---|---|---|---|
| **Mound AB** | 100% | 84.06% | 54.30% | 6.20% | 5.24% | 96.36% | 100% |
| **Mound E** | not excavated | 12.52% | 43.02% | 53.89% | 39.02% | not excavated | not excavated |
| **Mound ET** | not present | 3.42% | 2.68% | 35.54% | 40.36% | not excavated | not excavated |
| **Mound F** | not present | not present | not present | 4.36% | 15.38% | 3.64% | not excavated |

or survey units (lots) that have been assigned to date, around 4000 contained at least one stone or metal artifact. About three-quarters (n = 3024) of those lots represent chronologically secure strata. The percentages in the third column of the figure were calculated based upon the number of individual lots containing stone within each period.

Both methods of calculation result in overall similar distribution patterns. It is at once evident that stone artifacts belonging to Period 3C dominate the dateable assemblage (comprising around 60% of the total). This is not at all surprising as most of the Harappa's surface area consists of strata belonging to that sub-period and therefore nearly every excavation trench placed at the site encountered those levels. Stone from earlier periods was recovered in only a limited number of trenches. The fourth column of Figure 4.10, which shows the numbered trenches and/or other excavation areas that are associated with each chronological phase, quite clearly illustrates phenomenon. The considerably smaller percentages for the others periods is due to either their comparatively limited exposure (periods prior to 3C) or lack of preservation (periods after 3C). It may seem counterintuitive that the Period 3A assemblage is smaller than the even more deeply buried periods 1 and 2. However, this is due to the fact that most (or all in the case of Period 1) of the stone artifacts representing the initial two chronological phases at Harappa come from the large-scale exposures of Trench 39, which was placed at a point on the northern edge of Mound AB where the overburden of later levels was minimal. Substantially fewer Period 3 artifacts were recovered in that particular large trench than would normally be expected when exposing an area of Early Harappan levels of that size. Although Period 3A levels were reached in many more trenches, the areas actually exposed in each were very small.

Figure 4.11 details the temporal and spatial distribution of the rock and mineral assemblage among the main mounds at Harappa. Because one of the aims of this study is to compare acquisition and use patterns between parts of the site that may have been controlled by different social/political groups, the roughly seven percent of the assemblage that comes from cemetery and off-mound contexts, which cannot realistically be associated with one or another group, was excluded from the calculations for this particular table. With the focus on just the four main walled areas, the equities and, mostly, disparities in how the assemblage is distributed among them during the various periods become quite clear. Although

there is evidence for a Ravi Phase occupation in the area of what is the northwest corner of Mound E, all of the stone representing Period 1 presently comes from Mound AB. Similarly, evidence for a Late Harappan Phase occupation exists over large parts of the site but the only stone from secure Period 5 levels comes from a small area on Mound AB. Period 3A has the most equitable distribution of rock and mineral artifacts between the two largest habitation areas at Harappa (54% for AB vs. 43% for E) but, aside from Period 4/5, the smallest sized sub-assemblage of any phase (refer back to Figure 4.10). The largest rock and mineral sub-assemblage dates to Period 3C, but nearly 80% of it comes from the conjoined area of mounds E-ET. Artifacts from those mounds comprise nearly 90% of the sub-assemblage for Period 3B.

It is worth acknowledging that sub-assemblages recovered from different phases and/or mounds at Harappa are not necessarily equally representative samples of the contexts to which they belong. In order to begin to get a truly accurate picture of how representative they may or may not be in relation to each other, it would be necessary to know the total volume of the strata comprising each period (both for the site and for each mound) and compare that to the volume of excavated strata for each period. Calculations of this type have not yet been completed due to the complexity of Harappa's stratigraphy. In spite of that, informed comparisons between sub-assemblages can still be made as long as proper consideration is given to differences among the contexts under examination. For example, nearly 12% of the 32,365 stone or metal artifacts from secure contexts were recovered in a single trench that reached Ravi Phase levels, while roughly 60% of them came from 40 excavation areas that exposed Period 3C contexts (refer back to Figure 4.10). Judging from the temporal distribution pattern alone it might appear that the sub-assemblage for Period 1 at Harappa is not as representative of the Ravi Phase as the one for Period 3C is of that phase. However, the size disparity between these two chronological sub-assemblages is mitigated somewhat when it is recognized that the Ravi Phase occupation (estimated is have been at most 10 ha in area – Kenoyer and Meadow 2000: 56) was much smaller than that of Harappa Phase 3C (estimated to have been 150+ ha – Meadow and Kenoyer 2001: 26). As sets of artifacts belonging to different periods and areas are compared in the following section and throughout this book, every effort is made to similarly consider potential assemblage distribution biases in light of differences in the nature and extent of the temporal and spatial contexts under examination.

## Spatial and temporal variations in the rock and mineral assemblage

Having shown how Harappa's rock and mineral assemblage is distributed across the site, potential spatial and/or temporal variation of the "elements" that make it up can be properly examined and evaluated. In Figure 4.12, the major, minor and miscellaneous rock and mineral varieties at Harappa are cross-listed with the contexts in which they occur. Those present in a particular context are identified in the columns using the one or two letter code that signifies the mound or other part of the site where they were recovered. On the bottom row on the figure the total number of varieties present at Harappa in each phase is noted in bold print while the totals from each mound are in parentheses.

At first glance it would appear that, from Period 1 through Period 3C, there is a general trend toward greater diversity in terms of the varieties of rocks and minerals used by Harappans. Fourteen varieties have been recovered in both the Ravi and Kot Diji phases (although not entirely the same ones). Then, after a slight drop in Period 3A, they increase to 19 varieties in Period 3B and by Period 3C at least 22 were being used. The steep drop to 11 in Late Harappa (Period 4/5) levels could be taken as evidence of a dramatic reduction of acquisition networks during that period.

**Figure 4.12** Distribution of rock and mineral varieties by period and by mound or other* areas
*(C = Cemetery, S = Sarai)

| **Variety ↓ / *Context →*** | ***1*** | ***2*** | ***3A*** | ***3B*** | ***3C*** | ***4/5*** | ***surface / disturbed*** |
|---|---|---|---|---|---|---|---|
| 1. Steatite | AB | AB, E, ET | AB, E, ET, C | AB, E, ET, F, C | AB, E, ET, F, C, S | AB, F | AB, E, ET, F, C, S |
| 2. Chert | AB | AB, E, ET | AB, E, ET | AB, E, ET, F, C | AB, E, ET, F, C, S | AB | AB, E, ET, F, C, S |
| 3. Agate-Jasper | AB | AB, E, ET | AB, E, ET, C | AB, E, ET, F, C | AB, E, ET, F, C, S | AB | AB, E, ET, F, C, S |
| 4. Copper | AB | AB, E, ET | AB, E | AB, E, ET, F | AB, E, ET, F, C, S | AB | AB, E, ET, F, S |
| 5. Siliclastic rocks | AB | AB, E | AB, E | AB, E, ET, F, C | AB, E, ET, F, C, S | AB | AB, E, ET, F, C, S |
| 6. Vesuvianite-grossular | AB | x | x | E, ET | AB, E, ET, F, C, S | AB | AB, E, ET, F |
| 7. Igneous-metamorphic | AB | AB, E | AB, E, C | AB, E, ET, F, C | AB, E, ET, F, C, S | AB | AB, E, ET, F, C, S |
| 8. Gypsum | AB | AB | AB, E, ET | AB, E, ET, C | AB, E, ET, F, C, S | x | AB, E, ET, F, S |
| 9. Limestone | x | AB | x | E, ET | AB, E, ET, F, C, S | x | AB, E, ET, F |
| 10. Lapis lazuli | AB | AB, E | AB, E | E, ET, C | AB, E, ET, F, C | AB | AB, E, ET, F |
| 11. Crystalline quartz | x | AB | AB, E | E, ET, F | AB, E, ET, F, C | x | AB, E, ET, F, S |
| 12. Gold | AB | AB, E | AB, E | E, ET, C | E, ET, F, C | x | AB, E, ET, F, C |
| 13. "Ernestite" | x | x | x | ET | E, ET, F, C | x | E, ET |
| 14. Amazonite | AB | AB | x | F, C | AB, ET, F | AB | AB, ET |
| 15. Ochre Minerals | AB | AB, E | E | E | E, ET, F | AB | AB, E, ET |
| 16. Lead | AB | x | x | C | E, ET, F | x | E, ET, F |
| 17. Serpentine | x | x AB | E | AB, E | E, ET, F, C | x | AB, E, ET |
| 18. Almandine garnet | AB | x | x | x | x | x | E |
| 19. Calcite | x | x | x | x | x | x | ? |
| 20. Fluorite | x | x | x | x | E | x | E, ? |
| 21. Fossil foramina | x | x | x | x | C | AB | x |
| 22. Kaolinite | x | x | x | x | x | AB | x |
| 23. Mica | x | x | x | x | E, C, S | x | x |
| 24. Nephrite | x | x | x | C | x | x | x |
| 25. Prehnite | x | x | x | x | ET | x | x |
| 26. Sulfur | x | x | x | x | x | x | ET |
| 27. Tourmaline | x | x | x | x | x | x | (AB-E) |
| 28. Turquoise | x | x | x | C | ET, F | x | AB, E |
| total varieties present | 14 | 14 – AB(14) E(9) ET(4) | 12 – AB(10) E(12) ET(4) | 19 – AB(8) E(14) ET(13) F(8) C(12) | 22 – AB(12) E(18) ET(19) F(17) S(10) | 12 | 23 – AB(17) E(20) ET(18) F(13) |

It would also appear that there were synchronic differences in the number of varieties to which residents living on different mounds at Harappa used or had access. Except for Period 2, in all chronological phases for which stone has been recovered in multiple areas of the site there are a greater number of varieties found on conjoined mounds E and ET.

The patterns evident in Figure 4.12 cannot simply be taken at face value, however. When they are considered in relation to figures 4.9 through 4.11, it is clear that there is a direct correlation between the spatial and temporal distribution of the assemblage and its diversity in different periods and areas. Quite simply, those mounds and phases from which the largest sub-assemblages were recovered are also the ones that exhibit the greatest diversity of rock and mineral varieties. Those with the smallest-sized sub-assemblages are the least diverse. So although it might be tempting say that Harappans dwelling on mounds E-ET during Period 3C had access to and were utilizing a much wider range of rocks and minerals than their counterparts in other periods and areas of the site, I do not think that such a statement is tenable. Much of the apparent diversity in that particular period/area is due to the presence of many miscellaneous and lesser abundant minor varieties that are absent in other contexts. However, there was a much greater probability that those rarer materials would be recovered in Period 3C levels on E-ET simply because 60% of the dateable assemblage belongs to that period and 80% of that comes from those mounds. When a similar amount of strata is eventually unearthed for other contexts it is quite probable that many of the scarcer varieties also will be encountered in them. Of course, some of those miscellaneous rocks and minerals actually may have been used for the first time by Harappans dwelling on Mounds E-ET during Period 3C. However, because of the small number of artifacts (all but one of the miscellaneous varieties is represented by three or fewer examples) and the clear bias in the assemblage distribution toward that particular area/period, such an interpretation would be rather tenuous indeed. Convincing evidence for *genuine* variations (i.e., those stemming from the behaviors of Harappans) between sub-assemblages from different spatial and temporal contexts is better sought by examining varieties for which a much greater number of examples have been recovered.

The five major rock and mineral varieties at Harappa are present in all of the site's chronological phases. The few spatial contexts where some have not been found (such as the absence of siliciclastic rock artifacts on Mound ET during periods 2 and 3A) are, not surprisingly, those areas where limited exposures have produced extremely small sub-assemblages. Examples almost certainly will be found in those areas when more excavation takes place and, therefore, I believe it can be safely stated that Harappans of all periods and parts of the site probably had access to each of these material varieties. Possible temporal and spatial variations in the use of certain types of each of the major rock and minerals varieties are explored in upcoming chapters.

Many of the minor rock and mineral varieties display clear spatial and temporal variations, some of which are likely genuine, others of which are probably not. The uneven distribution through the assemblage of certain less abundant minor varieties, such as lead and serpentine, likely relates to the same issue of low recovery probability that affects the miscellaneous varieties. Similarly, the absence of nine of the twelve minor varieties from Period 3B contexts on Mound AB is almost certainly a result of sample size (only around 6% of the dateable assemblage from that period belongs from Mound AB – refer to Figure 4.15). Materials like gold, lapis lazuli, gypsum (alabaster), igneous-metamorphic rocks and ochre minerals each seem to have been used in all chronological phases and in most areas of the site. On the other hand, the "Ernestite," vesuvianite-grossular and limestone sub-assemblages are concentrated in




**Figure 4.13** Map showing the nearest sources of the major, minor and miscellaneous rock and mineral varieties found at Harappa (numbers and symbols correspond to varieties listed in column one of Figure 4.12).

certain contexts in ways (previously noted in this chapter) and, importantly, *in amounts* that suggest the use of these materials was genuinely variable over time and space at Harappa. Further details relating to the use patterns of these three varieties of stone are featured in the upcoming chapters devoted to them.

## INTERPRETATION OF THE ROCK AND MINERAL ASSEMBLAGE'S COMPOSITION AND VARIABILITY

In this final section, I consider the composition and variability of Harappa's rock and assemblage as a whole in relation to the three lines of inquiry outlined

in Chapter 1.

*Who in the ancient Greater Indus region or beyond were the residents of Harappa interacting with when they acquired rock and mineral resources? What was the extent of those inter-regional relationships/acquisition networks?* It was not the purpose of the chapter to make the provenience determinations necessary to link stone and metal artifacts from Harappa to their probable geologic sources. However, much can be still be learned about the possible extent and direction of the acquisition networks in which the site's residents participated by examining where potential raw material sources occur in relation to the site and to each other. Also, the geologic occurrences of at least one material variety – lapis lazuli, are sufficiently restricted enough that it is possible to confidently propose the existence of a specific source-to-site network during the periods in which it is present.

For her study of resource access and inter-regional interaction in the ancient Indus region, Marcia Fentress created a map of northwestern South Asia (Fentress 1976: Map 7) that is useful for conceptualizing distance/direction relationships and possible travel times between major Indus cities on the alluvial plains and the surrounding highland regions where rock and mineral resources occur. On it she placed concentric circles extending outward from Harappa and Mohenjo-daro at intervals of 100, 300 and 500 kilometers. Using the same distance intervals centered just on Harappa, I have created a modified version of that map (Figure 4.13) on which numbers and symbols (corresponding to the varieties listed in the first column of Figure 4.12) are placed that identify the *nearest* locations where each of the rock and mineral varieties (and a few important macroscopically distinct sub-varieties or *types*) recovered at the site can be found. Half of them occur within a 300 km radius (around a 10-day walk in Fentress's estimation) and most of the rest are located within 500 km (≈ 20-day walk). Only for lapis lazuli, turquoise and the carnelian variety of agate would it have been necessary to travel farther than that. Most significantly, all of the nearest sources are located within a broad, semi-circular zone that begins directly west of Harappa in the Sulaiman Range and extends through regions to the north and northeast of the site. It should be stressed that the locations noted are not necessarily the sources that Harappans used (not all are the most accessible or the ones that contain the best quality material). They are the closest, however, and plotting them on the map in this way clearly illustrates how they are concentrated in the highland areas west and north of the upper Indus Basin. In terms of simple site-to-potential-source distance, Harappa is most decidedly oriented in these directions. It is, therefore, quite reasonable to expect that many of the rock and mineral varieties recovered at the site may have been originally derived from sources within this zone. I believe one variety – lapis lazuli, almost certainly was.

In Appendix 4.4, I argue that the Badakhshan area deposits of northern Afghanistan were the sole sources of lapis lazuli for consumers in ancient South Asia. Some degree of interaction between that source region and the Punjab from the fourth through second millenniums BC second is, therefore, indicated by the presence of artifacts made of this stone in every one of the Harappa's chronological phases and sub-phases. Whether or not that interaction was direct or indirect and the route(s) along which it occurred is unclear. During the Early Harappan periods (ca. fourth and early third millenniums BC), residents of Harappa may have acquired lapis lazuli indirectly through long-distance trade with Helmand Tradition peoples, such as those at Shahr-i-Sokhta, who clearly seem to have been involved in its processing and transportation at that time (Tosi 1974a). The presence of Indus Civilization peoples at Shortughaï (Francfort 1989) in northern Afghanistan might well indicate that Harappans had direct access to that material during Period 3 (although the site was actually several hundred kilometers downstream and a few thousand

meters below the actual deposits). Regardless of how it was acquired or how much was recovered, lapis lazuli is present throughout the sequence at Harappa and, because it was almost certainly from a source to the north of the site, it opens the possibility that many other rock and mineral resources were also being obtained from sources in that general direction.

*How did the patterns of inter-regional interaction/ acquisition exhibited by residents of Harappa change over time?* Once again, it was not the intent here to make the provenience determinations necessary to diachronically examine patterns of interaction. Comparing assemblage compositions from period to period, however, gives the impression that, in general, there was not a great deal of change over time in the basic suite of materials used at Harappa. Dilip Chakrabarti's assertion (1998: 51) that there was "hardly any major change" in basic suite of raw material types used by Early Harappan and Harappan peoples basically holds true – at least at Harappa itself. The abundant varieties are present throughout the site's entire sequence while less abundant ones likely vary because of low probability of recovery. Exceptions may be limestone, "Ernestite" and vesuvianite-grossular, the use of which seems to have been most intense during periods 3B and 3C. The reasons for this have been or will be discussed but, suffice to say, I do not think they have to do with newfound access to the regions where those materials occur. Rather, their use likely relates to changing cultural preferences (discussed in Chapter 11 for limestone) or technological innovation (the development of "Ernesite" drills).

*Did synchronic variations in patterns of rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?* It appears that, by and large, people living in all parts of Harappa had access to the same varieties of rocks and minerals. This is not to say that they were acquiring them from the same sources or that they were using them in the same way; only that copper, steatite, chert, alabaster, etc, etc, are pretty much found in all parts of the site. Most instances where a particular material is absent from a mound is likely due to low probability of recovery for less abundant varieties in areas that have not been as extensively excavated. Vesuvianite-grossular and "Ernestite," which are concentrated on mounds E-ET, again seem to be exceptions. This may indicate that access to these particular materials was controlled by the residents of those areas (this issue is returned to again in chapters 9 and 13).

## CHAPTER CONCLUSION

Harappa's large and diverse rock and mineral assemblage has been organized and examined on a broad scale. In the next eight chapters, I attempt to identify the inter-regional interaction networks through which specific material varieties were acquired.

# CHAPTER 5

# GRINDINGSTONE ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: THE IMPORTANCE OF GRINDINGSTONES

Groundstone implements are, in terms of total weight, by far the most abundant kind of stone artifact found at Harappa. Included in this category are querns, mortars, mullers, pestles, whetstones, burnishers and adzes. Examples have been recovered in abundance from every chronological phase and on every habitational mound at the site. The only lithic categories containing more individually tabulated artifacts are those for steatite, chert and agate, which is certainly due in large part to the fact that a great deal of debitage is generated in the process of turning those raw materials into finished products. In this chapter, I examine the networks through which residents of Harappa acquired the largest, heaviest and perhaps most important kinds of groundstone implements - the querns and mullers that are essential for both processing foods and for performing many craft activities.

Preparing cereals for human consumption is a multi-stage procedure that usually involves several different kinds of implements. Evidence for cereal processing at Harappa mainly exists in the form of stone querns and hand mullers. Other implements used may have been made of perishable materials that have not survived. The use of wooden mortars and pestles to de-husk cereals by pounding prior to further processing with stone querns is documented in Egypt during this period (Nesbit and Samuel 1996: 51-53). The prevalence of querns and mullers at the site might reflect the differential preservation of processing implements and/or that some processing stages took place away from of the city. These objects were, nevertheless, indispensable tools for preparing staple cereals (and many other foods) and so having a reliable supply of them would have been especially critical to the development and maintenance of an urbanized society supported by agricultural surplus.

The role of craft activities in the economic and political development of complex societies in general (Costin 1991; Helms 1993) and the Indus Civilization in particular (Kenoyer 1989, 1992a) cannot be underestimated. It is therefore important to note that querns and mullers were also necessary for modifying a range of non-consumables such as wood, shell, bone, hide and minerals (Dubreuil 2004). In a burgeoning center of craft production like Harappa a reliable supply of these implements would have been essential.

Querns and mullers (hereafter referred to together as "grindingstones") are the largest and heaviest utilitarian artifacts found at Harappa. Some of the few complete querns that have been recovered weigh in excess of 20 kg. Transporting these bulky items from distant sources to the site in the amounts necessary to fulfill the requirements of an urban population would have required some form of organized effort. As Harappa grew, it certainly would have demanded an increasing expenditure of energy over time. When that reality is considered together with the requisite need for grindingstones to process staple foods and in craft production (plus the fact that there are no local stone sources whatsoever), it makes this category of artifact an excellent one with which to investigate issues relating to economy, transportation capabilities and early urban lifeways at Harappa.

I begin by first examining the regions within and surrounding the upper Indus Basin that would have




**Figure 5.1** Sites and source areas discussed in this chapter.

been the most likely sources of the grindingstones used at Harappa. Then I provide the details and results of a large-scale study in which geologic materials from those sources were visually compared to grindingstones recovered during excavations and surveys at the site. Lastly, I examine the geologic provenience determinations made in that study in relation to Harappa's location, chronological sequence and spatial layout.

## POTENTIAL GRINDINGSTONE SOURCES IN AND AROUND THE UPPER INDUS BASIN

Querns and mullers can be fashioned out of different varieties of geologic material. At Harappa grindingstones made from sandstone or quartzite were most common, but other sub-varieties of igneous and metamorphic rocks were also used. In this section, the potential grindingstone sources of the upper Indus Basin are reviewed in order of their proximity to the site. Multiple locations in each of the source areas discussed below were visited for this study. Samples representing the range of material sub-varieties present at those locations were collected and stored at Harappa for eventual comparative studies. All sources, regions and sites discussed in this chapter are identified on Figure 5.1.

### The Kirana Hills

The Kirana Hills would have been nearest source of grindingstone (or of any variety of stone) for residents of Harappa. These Precambrian outcrops emerge from the alluvial plain near the center of the Ravi-Chenab doab, 120 km to the northeast



**Figure 5.2** The southernmost Kirana Hills outcrop at Shah Kot - 120 km north-northeast of Harappa. For residents of Harappa, this would have been the closest source of stone of any kind. Note that the outcrop and the historic period site that abuts it are being destroyed by quarrying.



**Figure 5.3** One of the northernmost Kirana Hills outcrops near Sargodha.



**Figure 5.4** The Chiniot (foreground) and Rabwa-Chenab Nagar outcrops (background) at the point where the Chenab River passes between them.



**Figure 5.5** Rock engravings at Rabwa-Chenab Nagar. Photo courtesy of Muzaffar Ahmad.

of Harappa at Shah Kot (Figure 5.2) and continue intermittently to around Sargodha (Figure 5.3), 150 km due north of Harappa in the Jhelum-Chenab doab. Some outcrops are composed mainly of metasedimentary rocks (quartzites, conglomerates and slates) while others are intrusive bodies of igneous materials such as andesite, dolerite, rhyolite and/or volcanic tuff (Alam *et al*. 1992). In the Gazetteer of the Jhang District (Punjab Government 1884: 15) it was reported that there were several quarries for "millstones, pestles and mortars" just north of Chiniot, near the point where the Chenab River passes between several Kirana outcrops at Rabwa (Figure 5.4). Rock engravings (Figure 5.5), reminiscent of those found across the Chilas and Hunza regions of Pakistan's Northern Areas (Jettmar 1991), have recently been documented in Rabwa area by Muzaffar Ahmad (personal communication 2010).

### The Sulaiman Range

A nearly complete sequence of Jurassic to Pleistocene sedimentary rocks (Akhtar and Masood 1991: 1) can be found beginning 220 km due west of Harappa in the extensive, north-south oriented Sulaiman Range (Figure 5.6). Monsoonal hill torrents, "heavily laden with detritus" (Punjab Government 1898: 2-3), have resulted in the formation of massive alluvial fans and boulder beds (Figure 5.7) that extend along the base of these mountains.

### The Salt Range

The Salt Range rises 225 km north of Harappa, abruptly marking the end of the Punjab Plain (Figure 5.8). Material for grindingstones could have been obtained from any number of the sandstone formations or boulder beds found here (Shah 1980). The pinkish-red to maroon colored sandstone of the Kherwa formation (Figure 5.9), which occurs along the southern base of the range is locally used as grindingstone today (Figure 5.10). I have observed artifacts composed of the very same material at the Early Harappan and Harappan period site of Musa Khel (Dani 1971: 32), located less than four kilometers to the southwest of the Salt Range.

### Bikaner area occurrences

Approximately 250 km directly south of Harappa, low outcrops of sandstone, shale and limestone (Pareek 1984) intermittently rise above the dunes of the northern Thar Desert around the city of Bikaner in northwestern Rajasthan. The famous red sandstone of Bikaner Palace was quarried (and is still today) from one such outcrop at Dulmera (Figure 5.11).

### The foothill zone of the Himalayas

The foothill zone of the outer Himalayas begins approximately 300 km northeast of Harappa at the Siwalik Hills (Figure 5.12). These hills extend continuously from the Potwar Plateau in northern Pakistan all the way to eastern India. Although the Siwaliks primarily consist of the sedimentary rocks, cobbles of igneous and metamorphic stone brought down from the Inner Himalayas can be found within the loosely consolidated conglomerates (Figure 5.13) and river beds of this zone (Kumar *et al*. 1991: 1-2).

### Tosham Hills and Aravalli Outliers

Nearly 350 km southeast of Harappa, in southern Haryana, India, a series of igneous outcrops emerges from the plains in the vicinity of the town of Tosham. Most of the hillocks in the area are composed of grey granite (Figure 5.14) of Precambrian age (Grover and Kumar 1980). The outcrop at Tosham (Figure 5.15) itself is made up of rhyolite, granite and metasedimentary rock and contains a polymetallic ore deposit (Murao *et al*. 2008) that has been pointed as a possible source of tin for the Indus Civilization (Kochhar *et al*. 1999).

Around 30 km further southeast of the eastern-most Tosham area outcrop begins the western-most outliers of Delhi quartzite, which is a formation that makes up large parts of the northern Aravalli



**Figure 5.6** The Sulaiman Range near Ft. Munro.



**Figure 5.7** Massive boulder beds at the base of the Sulaiman Range near Sakhi Sawar.



**Figure 5.8** The southern base of the Salt Range, Pakistan.



**Figure 5.9** Khewra sandstone, Salt Range, Pakistan.



**Figure 5.10** A man near Lille (central Salt Range) displaying a locally made Khewra sandstone muller.



**Figure 5.11** Red sandstone quarry at Dulmera, Bikaner District, Rajasthan.



**Figure 5.12** The Siwaliks near Chandigarh, Punjab, India.



**Figure 5.13** Sedimentary, igneous and metamorphic cobbles in the loosely consolidated conglomerate of the Siwaliks.



**Figure 5.14** The gray granite of Dharan Hill, near Tosham, southern Haryana, India.



**Figure 5.15** Tosham Hill, southern Haryana, India.



**Figure 5.16** Sandy-textured Delhi Quartzite from Kaliana Hill, Haryana, India.



**Figure 5.17** Grindingstone carver at Kaliana Village.



**Figure 5.18** Quern, muller and mortar made from Kaliana Hills Delhi Quartzite.

Mountain Range from New Delhi down to Jaipur. The Delhi quartzite that occurs as outcrops within and to south of the city of New Delhi typically has a highly silicious or "glassy" texture and, for this reason, would have made poor grindingstone. However, the material found in theF Delhi quartzite outliers in the vicinity of Kaliana village in the Bhiwani District of southern Haryana has a sandy texture (Figure 5.16) and, in a few places, an unusual "flexible" quality that actually permits the stone to be significantly deformed before it breaks (Pande and Gupta 1969). Its suitability as grindingstone is attested to by the continued existence of a local industry (Figures 5.17) devoted to manufacturing querns, mullers (Figure 5.18) and mortars using stone from outcrops in the area.

## DETERMINING THE GEOLOGIC PROVENIENCE OF HARAPPA'S GRINDINGSTONES

A large-scale geologic provenience investigation of querns and mullers was initiated following a preliminary study of grindingstone artifacts that took place during the HARP's 2000-2001 field season. That preliminary study had indicated that there were likely several distinct *types* of grindingstone present within the rock and mineral assemblage at Harappa. In this chapter, I use the word "type" rather than variety or sub-variety to refer to grindingstone material. A type is defined based on its visual appearance and/or the location/geologic formation where it occurs (so siliciclastic sedimentary rock is a variety, quartzite is a sub-variety and Delhi quartzite is a type). Examples of what appeared to be the different types of grindingstone from Harappa were included in the "traveling" set of archaeological samples (discussed in Chapter 3) that was taken around to institutions around Pakistan for comparative study. There they were evaluated by geologists with years of field experience in the potential source regions. Using their recommendations and identifications as a starting point, I undertook numerous field excursions in Pakistan and India over the next four years for the purpose of collecting comparative geologic samples. In addition to the six regions discussed in the preceding section, samples were collected from sources in Balochistan, Sindh, Gujarat, Jammu, the NWFP and Pakistan's Northern Areas as well as regions elsewhere in Rajasthan and Indian states in the western Himalayas. All samples collected in the field were brought to Harappa and, over time, a large set of geologic comparative materials was compiled.

By 2004, the geologic sample set was reasonably comprehensive and so a systematic comparison with grindingstone artifacts from Harappa could begin. While some form of quantitative analysis focusing on geochemical properties (isotopic compositions, elemental concentrations, etc) was undertaken on most varieties of stone and metal artifacts examined for this study, several factors made this unfeasible for grindingstones: no analytic instrumentation was available at Harappa; analyzing the entire assemblage using such techniques would have been prohibitively expensive; and physically removing material from each artifact for destructive analysis elsewhere was not possible. A series of petrographic thin sections from a selective sample of Harappan grindingstones representing each major material type were made at the Pakistan Museum of Natural History and will eventually be used to supplement this study. However, the provenience determinations made here were based solely on the qualitative comparison of the macroscopic characteristics of artifacts and source samples. Although visual analysis of stone artifacts, when used alone, does have limitations (Luedtke 1979: 745-46), it is rapid, cheap, non-destructive, can be done in the field on a large-scale and sometimes produces results that are as good or better than those obtained using more sophisticated methods (Moffat and Buttler 1986: 14).



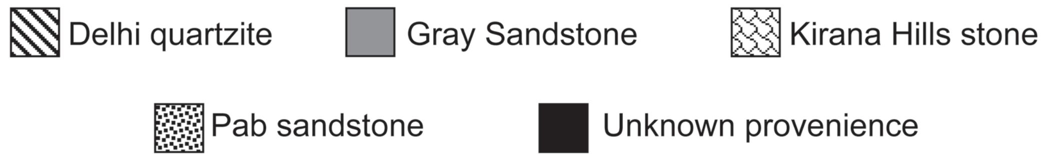
**Figure 5.19** Examining and recording grindingstones at Harappa.

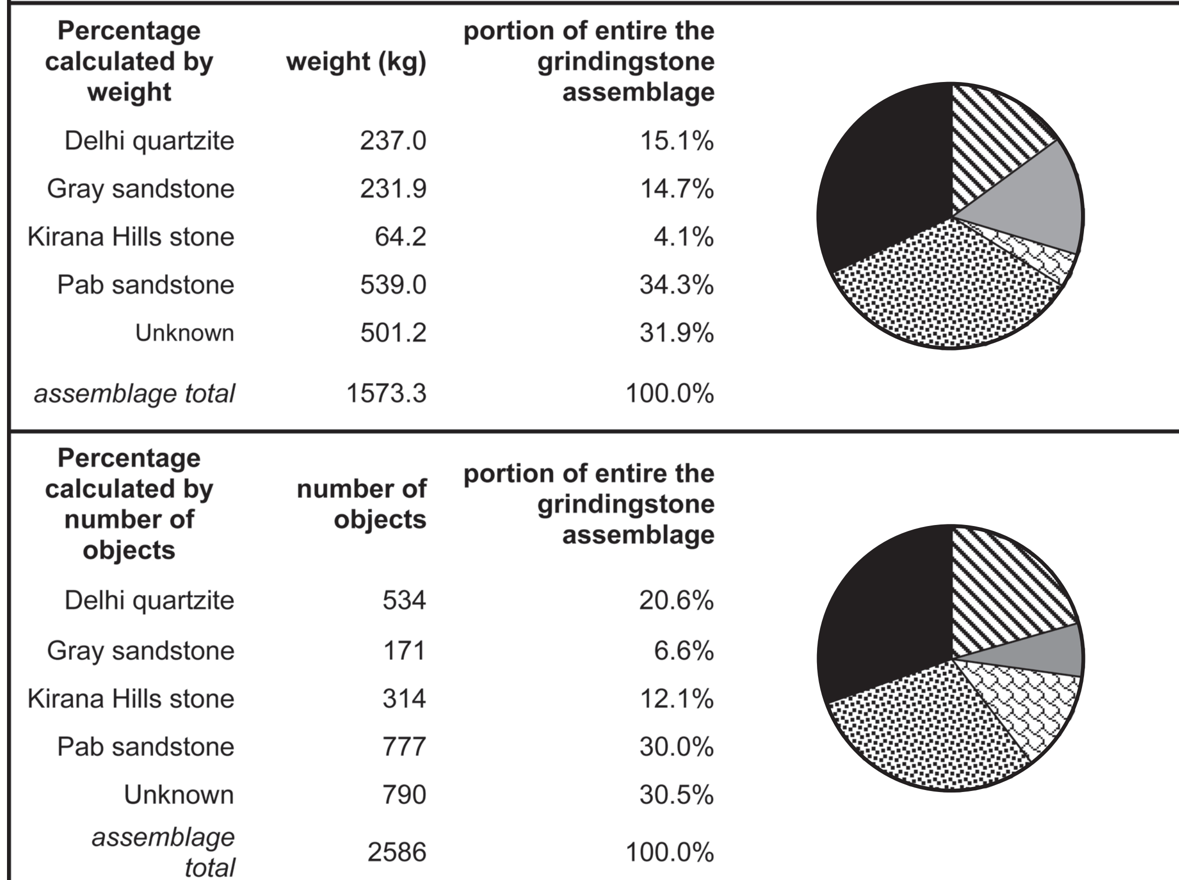
All querns and mullers (whole and fragmentary) recovered from excavations and surveys at Harappa (Appendix 5.1) along with those from previous excavations stored in the site museum's reserve collection (Appendix 5.2) were individually examined and recorded (Figure 5.19). In total, 2586 grindingstone artifacts were compared with geologic source samples and assigned a provisional geologic provenience based on an assortment of qualitative physical criteria including rock sub-variety, color, texture, grain size, patterning, visible inclusions, degree of silicification and toughness. Those that could not be confidently assigned a provenience using these criteria were classified as source "unknown."

## THE GEOLOGIC PROVENIENCE COMPOSITION OF HARAPPA'S GRINDINGSTONE ASSEMBLAGE

The overall composition, in terms of geologic provenience, of the grindingstone assemblage at Harappa is displayed, without reference to context or period, in Figure 5.20. Before proceeding, however, it is necessary to explain the manner in which the percentages found in the tables and charts used in this chapter were generated. Harappan grindingstones were tools that appear to have been used, broken, re-fashioned and re-used repeatedly. Thus, nearly all of the grindingstones recovered are in a fragmentary state. Some are almost complete – that is, they may only be chipped or slightly broken. However, even though multiple fragments that belong to the same implement have been refitted whenever possible, most of the assemblage consists of incomplete pieces what were clearly larger implements at one time. So this

**Figure 5.20:** Overall composition of the grindingstone assemblage at Harappa (without reference to period or context)



| Percentage calculated by weight | weight (kg) | portion of entire the grindingstone assemblage |
|---|---|---|
| Delhi quartzite | 237.0 | 15.1% |
| Gray sandstone | 231.9 | 14.7% |
| Kirana Hills stone | 64.2 | 4.1% |
| Pab sandstone | 539.0 | 34.3% |
| Unknown | 501.2 | 31.9% |
| *assemblage total* | 1573.3 | 100.0% |

| Percentage calculated by number of objects | number of objects | portion of entire the grindingstone assemblage |
|---|---|---|
| Delhi quartzite | 534 | 20.6% |
| Gray sandstone | 171 | 6.6% |
| Kirana Hills stone | 314 | 12.1% |
| Pab sandstone | 777 | 30.0% |
| Unknown | 790 | 30.5% |
| *assemblage total* | 2586 | 100.0% |

raises the question – when calculating the amounts of different grindingstone types present at Harappa, is it more suitable to generate percentages based on the number of individually tabulated artifacts or the total weight of artifacts in a particular category? For some of the figures below both methods are presented and it is evident that, in most instances, the resulting percentages are not dramatically different. Ultimately, however, it was decided that generating percentages of material types present at the site based upon weight, rather than on the number of individual fragments, would more accurately reflect the degree to which material from a defined source was being utilized in a certain area of the site or during a particular period. Nevertheless, the total numbers of artifacts present in each category are listed in the tables that accompany the figures so that anyone wishing to evaluate the data by tabulated artifacts may do so. Nearly seventy percent (68.1% by weight and 69.5% by number) of all querns and pestles at Harappa could be confidently assigned to one of the following four material *types*, which I discuss next in order of decreasing abundance: Pab sandstone, Delhi quartzite, gray sandstone and Kirana Hills stone.

### Pab sandstone

Sandstone from the Pab Formation (Figure 5.21 A) is, by weight (34.3%), the most common type of

raw material in Harappa's grindingstone assemblage. This Cretaceous sandstone has a sugary texture and macroscopically grades from solid brown to a distinctive gray-white color with small (< 3mm) regularly spaced brown patches (Figure 5.21, B). The grindingstones at Harappa that have been categorized as Pab sandstone, two of which can be seen in Figure 5.21 C & D, are highly variable visually. The majority are grey-white with the distinctive brown spots or speckles. In other examples the characteristic spots are muted and there is a prominent brown, wavy, banded pattern. Some simply have a uniform brown color. In numerous cases two or more such visual patterns are present *in a single grindingstone* – sometimes as sharply defined components and at other times gradually grading into one another. After inspecting a range of this material in the field and examining (and re-examining) nearly 800 examples at Harappa, I felt confident in my ability to recognize these variations and correctly assign material type and provenience. Although this method of categorization is admittedly subjective, I would argue that the results it produces are sound given the large number of samples and the striking visual and tactile differences between materials in each type-provenience category.

The most extensive and well-developed sequence of Pab sandstone occurs beginning 220 km due west of Harappa in the Sulaiman Range (Kassi *et al*. 1991). After a break of nearly 300 km beginning near Balochistan's northern border with Sindh, the Pab Formation appears again over 600 km to the southwest of Harappa in the Las Bela and Khuzdar districts of southern Balochistan. The assumption made here is that the majority of Pab grindingstones identified at the site probably derived from the closer occurrence in the Sulaimans. Quarrying grindingstone directly from formations in the mountains themselves would have almost certainly been unnecessary during the proto-historic period as large cobbles suitable for querns and pestles could have easily been obtained from the alluvial fans or stream beds of the foothills that line the range. For this reason it is difficult to state precisely at what point or points along that approximately 300 km long north-south running mountain range that Pab sandstone used at Harappa was obtained. The site of Dhera, which has cultural affinities with Early Harappan cultures of the Punjab Plain and the adjacent Balochistan highlands, is located in this foothill region adjacent to a cobble-filled perennial hill torrent emanating from the central part of the Sulaiman Range (Siddique 1996). I observed Pab sandstone querns and mortars in a recent collection from the Harappan Period site of Ghandi Umar Khan (Khan *et al*. 2000), which lies near the foothills of the northern end of the Sulaiman Range.

The sugary texture and toughness of Pab sandstone makes it exceptionally well suited for grinding purposes. It is widely used for this purpose in modern Pakistan and "is also exported to Arabian countries" (Khan, M.A. *et al*. 1991: 223). During a visit to the city of Mardan in the NWFP, I visited a workshop where rotary millstones were being carved (Figure 5.22). Despite the fact that there are no lack of local stone formations in the NWFP from which millstone material could have been acquired, I was told that the stone they were using – Pab sandstone (Figure 5.23), was transported over 450 km (as the crow flies) from the Ft. Munro area of the Sulaiman Range to Mardan. The unmatched quality of this particular material made transporting the heavy stone long distances and in large quantities worth the effort and expense.

That same sentiment may have held true in Harappan times as well. I have noted Pab sandstone in collections made by Dr. Rita Wright from the Early Harappan (Kot Dijian) Period and Harappan Period sites found along the old bed of the Beas River (Wright *et al*. 2002; Schuldenrein *et al*. 2004). The majority of the grindingstones from Mohenjo-daro (Figure 5.21 E) that are stored in the collection of the Department of Archaeology and Museums,

**Figure 5.21** The Pab Formation, details of the types of sandstone found in it and examples of Pab sandstone artifacts from Harappa and other sites.



**A**. Exposed section of Pab Sandstone in the Sulaiman Mountains near Ft. Munro, D,G. Khan District, Punjab.



**B**. Brown (left) and speckled (right) types of Pab sandstone in the Sulaiman Range.



**C**. Pab sandstone quern (#318) from M.S. Vats' excavations at Harappa.



**D**. Pab sandstone muller (H95/5802-8) from Harappa, Mound ET, Period 3C.



**E**. Pab sandstone hand muller from Mohenjo-daro. Department of Archaeology and Museums Excavation Branch Collection.



**F**. Pab sandstone quern fragment on the surface at the Harappan Period site of Ganweriwala, Cholistan. [10 cm scale]



**Figure 5.22** Workmen carving millstones out of Pab sandstone.



**Figure 5.23** Detail of Pab sandstone millstone at Mardan showing a mixture of both brown-speckled and homogenous brown material.

Government of Pakistan's Excavation Branch in Karachi are made of Pab sandstone. Similarly, most of the grindingstones that I encountered on the surface of the as yet unexcavated Harappan period city of Ganweriwala (Figure 5.21 F) in the Cholistan region were composed of Pab sandstone. Fully one-third of all grindingstones recovered at Harappa are Pab sandstone and I suspect the same may be true when the full assemblages at Mohenjo-daro and Ganweriwala are examined as well. I have even seen a handful examples of Pab sandstone grindingstones during my ongoing study of stone and metal artifacts from the site of Rakhigarhi, which lies approximately 550 km east of the Sulaiman Range.

### Delhi quartzite

The second most common type of grindingstone at Harappa (15.1% by weight) appears to be the type of Delhi quartzite found only in the westernmost outliers of the Aravalli Mountains, located in southern Haryana (discussed above). Unlike the glassy, highly silicified gray-colored material that is typical of Delhi quartzite elsewhere in the Aravallis, the stone from these outcrops in the vicinity of Kaliana and Makanwas villages (Figure 5.24: A) in the Bhiwani district has a sugary texture, is red-pink to pinkish gray in color and is crisscrossed with thin hematite and quartz filled fractures (Figure 5.24: B). None of the other geologic formations immediately surrounding the upper Indus Basin contain material that even remotely resembles this distinctive type of quartzite. Grindingstones made of this stone at Harappa (Figure 5.24: C & D) are easily identifiable.

In certain places, the Delhi quartzite from these Aravalli outliers has an unusual "flexible" quality that may make it especially good stone for use as querns and mullers. Describing stone from the Kaliana outcrop, the geologists Pande and Gupta wrote:

> If one of the specimens which exhibits this peculiarity in any marked degree be examined, it will be found to yield with readiness to any external force applied, and it can be stretched, compressed or bent in any direction with the greatest ease up to a certain point beyond which the force is released along fractures (Pande and Gupta 1969: 589).

A grindingstone composed of Delhi quartzite with some degree of flexibility may be less likely to fracture under the stress of grinding and pounding than would a more ridged type of sandstone-quartzite. In future studies it would be very informative to conduct mechanical stress tests comparing this and the other types of grindingstones as a way to gage the "quality" of the different materials used at Harappa. Poor quality (a tendency to fracture under the stress of grinding and pounding) may perhaps be one of the reasons why (as we shall see below) certain types of grindingstone material become less represented in Harappa's assemblage over time.

The northernmost of these Delhi quartzite outliers is located 389 km southeast of Harappa but is only 29 km south of the site of Harappan period site of Mitathal (Bhan 1969). I have observed this type of quartzite in abundance on the surface and/or in collections from Mitathal and several other Early Harappan and Harappan period settlements that lay between the Delhi outliers and Harappa including Siswal (Figure 5.24: E), Kalibangan (Figure 5.24: F), Banawali, Farmana and Lohari Ragho. The Indus city of Rakhigarhi (Nath 1998) is located 75 km north of these outcrops. A large mortar and several querns recovered from that site on display at the National Museum in New Delhi are very clearly composed of the Kaliana area type of Delhi quartzite. In fact, while my study of the grindingstones from Rakhigarhi is presently incomplete, around 90% of the 650 examples I have documented thus far are also composed of this type of stone.

**Figure 5.24** Delhi quartzite outliers in southern Haryana, detail of stone types found there and examples of Delhi quartzite artifacts from Harappa and other sites.



**A**. Delhi Quartzite outliers near Kaliana, Bhiwani District, Haryana.



**B**. Detail of Delhi quartzite at Kaliana.




**C**. Delhi quartzite saddle quern fragment (H96/7205-2) from Harappa, Mound AB, Period 3 or later.




**D**. Delhi quartzite flat quern (H95/5181-1) from Harappa, Mound E, Period 3C.




**E**. Delhi quartzite quern from the Early Harappan site of Siswal, Hissar District Haryana. This artifact was unearthed by and is in the possession of, the farmer whose fields now cover the surface of the site.



**F**. Delhi quartzite fragment on the surface of the Harappan site of Kalibangan, Hanumangarh District, Rajasthan.

### Gray sandstone

The next most common type of grindingstone material at Harappa (14.7% by weight) is an extremely dense and tough gray sandstone (Figure 5.25 A & B). It is clear from an examination of complete artifacts and larger diagnostic fragments that most, if not all, querns and mullers composed of this material were made from water-rounded cobbles rather than stone that was quarried and then chiseled into shape. Cobbles of this description are found beginning 350 km east-northeast of Harappa, both within the formations of the Siwaliks foothills (Srikantia and Bhargava 1998: Chapter 5) and in the beds of Chenab, Beas, Sutlej and Ghaggar rivers (Figure 5.25 C & D) at the places where they meet the Punjab plain (*personal observation*). Importantly, several Harappan and/or Early Harappan settlements are located near these debouchures. The site of Manda is located in the Siwalik Foothills of Jammu at the northernmost navigitable point of the Chenab River (Joshi and Bala 1982). Harappan remains were also unearthed at Chandigarh, not far from where the Ghaggar River meets the plains (IAR 1985-86: 15). Ropar, Bara, Kotla Nihang Khan and Dher Majra are all proto-historic sites found within 10 km of the point at which the Sutlej River leaves the foothills (Prüfer 1956; Sharma 1982). Most of the grindingstones visible on the surface at Ropar (Figure 5.25 E) and on display in its site museum have clearly been made from river cobbles of this type of gray sandstone (*personal observation*). Cobbles of this material could have easily been transported downstream to Harappa and other plains settlements via the rivers of the upper Indus Basin. I have observed identical gray sandstone grindingstones on the surface of and/or in collections from Indus sites in Haryana including Banawali (Figure 5.25 F) (Bisht 1982), Lohari Ragho (Garge 2006) and Rakhigarhi (Nath 2001).

### Kirana Hills stone

The final and least abundant overall by weight (4.1%) of the four major identifiable grindingstone material types at Harappa is from the Kirana Hills. Kirana Hills stone, in terms of grinding purposes, is of decidedly inferior quality when compared to the other three material types described above – e.g., it is much more friable and, thus, breaks easier and produces many fragments. This then is an instance where the choice to consider material usage by weight rather than by number of individual artifacts tabulated makes a significant difference in how the composition of the overall grindingstone assemblage appears. For example, gray sandstone is very compact and tough and many more complete or nearly complete artifacts made from that type of material have been recovered as compared to Kirana Hills stone artifacts, which are nearly always found as fragments. When judged by number of fragments present, Kirana Hills stone accounts for 12.1% of the grindingstone assemblage, making it, instead of gray sandstone, which by number only accounts for 6.6% of the assemblage, the third most common type in the assemblage. Conceivably, the exact same amounts of both material types could have been brought to the site and used. However, using the more friable stone from the Kirana Hills would have almost assuredly resulted in more pieces of debris. It is for this reason that, in most cases, I have chosen to evaluate grindingstone source usage by weight instead of number.

Within the Kirana Hills, the composition and characteristic of stone are variable from outcrop to outcrop (Alam *et al*. 1992). Two different sub-types seemed to have been in use at Harappa. At certain outcrops, such as those found at Shah Kot, Sangla Hill (Figure 5.26 A) and some locations around Chiniot and Sargodha, a fine grained grey-green mottled, hematite-stained meta-quartzite is the dominant material (Figure 5.26 B). The grindingstone artifacts recovered at Harappa that are made from this material (Figure 5.26 C) are invariably fragmentary. No complete examples of querns or mullers have been found. At several places in the Sargodha area

**Figure 5.25** Gray sandstone artifacts at Harappa, rivers draining the Himalayas, cobbles found in their beds and gray sandstone artifacts at other sites.




**A**. Gray sandstone flat quern (#8841) from Vats' excavation at Harappa.




**B**. Gray sandstone muller (H94/5502-61) from Harappa. Mound ET, Period 3B.



**C**. Cobbles in the bed of the Ghaggar River at the point near Chandigarh where it leaves Himalayas.



**D**. Gray sandstone cobbles in the bed of the Sutlej River, 2km from the Harappan period site of Ropar.



**E**. Gray sandstone saddle quern on the surface of Harappan period site of Ropar, Ambala District, Punjab.




**F**. Gray sandstone muller on the surface of Harappan period site of Banawali, District Hissar, Haryana.

and again in the hills straddling the Chenab River near Rabwa (Figure 5.26 D), quartzite occurs that is gray-red to purplish-gray in color and has a coarse, conglomeritic texture with small clasts of cherty material (Figure 5.26 E). Grindingstones made from this conglomeritic quartzite (Figure 5.26 F) are found more frequently at Harappa than are examples of the fine grained sub-type. Also, several examples of complete mullers and nearly complete querns made from conglomeritic Kirana stone have been recovered, which suggests that they were more durable.

Although it would have taken a resident of Harappa several days to walk the 120 to 150 km distance to the Kirana Hills, there are a handful of Early Harappan and Harappan period settlements that are relatively close to that formation's southernmost outcrops. These include Khadin-wala (Dar 1983) and a cluster of eight other recently discovered proto-historic sites in the Ravi-Chenab doab or Sandal Bar (Qasim 2002), which are located 15 to 25 km south and west of the Shah Kot outcrop along what may have been the former watercourse or a tributary of the Ravi River. Harappan peoples making a journey to and from the site of Manda in the foothills of Jammu via the Chenab would have passed between the outcrops in the Rabwa-Chiniot area. Kirana Hills stone seems to have also been transported to settlements in regions beyond Harappa. I have observed a numerous fragments of what appears to that material in Beas Survey (Wright *et al.* 2002) collections from Early Harappan and Harappan Period sites along the old bed of the Beas River, some of which lie as far as 275 km away from the outcrops (Schuldenrein *et al.* 2004).

#### "Unknown" Provenience

Slightly more than thirty percent (31.9%) of the grindingstones in the assemblage could not be confidently assigned to any specific geologic formation based on macroscopic characteristics alone and so were categorized as having an "unknown" provenience. A great many of these were igneous and metamorphic rocks such as dense black basalt, gabbro, gneiss and diorite that are visually identical to other rocks of the same sub-varieties found in numerous regions surrounding the Indus Valley. Several gray or pink granite grindingstone fragments were recorded that could have been from the Tobra boulder beds of the Salt Range (Shah 1980: 12), the Nagar Parker outcrop of southern Sindh (Jafry and Ahmad 1991), outcrops in the Jhunjhunu district of northern Rajasthan (Basu 1982) or several other locations including the Tosham Hills outcrops. Likewise, the numerous highly silicified white quartzite cobbles encountered could have come from as near as the Dok Pattan Formation of the Siwaliks (Iqbal 1994) or one of several formations in the North Delhi Fold Belt of the Northern Aravallis (Sinha-Roy *et al* 1998: 129-140). Chemical composition, isometric dating of igneous rocks and/or petrographic analyses may, in the future help, to resolve the geologic proveniences of many of these "unknown" types.

### DIACHRONIC AND SPATIAL VARIATIONS IN GRINDINGSTONE SOURCE UTILIZATION AT HARAPPA

Nearly 43% of the 2586 querns and mullers from Harappa evaluated in this study were recovered during surface surveys or came from disturbed or secondary contexts such as brick robber trenches or the sifting of back dirt piles from past excavations. However, 1475 of the grindingstones were excavated from secure, stratified contexts spanning Harappa's five main periods of occupation. This assemblage essentially represents a 100% sample of grindingstone artifacts in excavated areas. With such a substantial dataset it is possible to address questions relating to diachronic and spatial variation in grindingstone source utilization at Harappa with a reasonably high

**Figure 5.26** Kirana Hills outcrops, details of two types of stone found there and examples from Harappa.



**A**. Kirana Hills outcrop at Sangla, District Sheikhupura, Punjab.



**B**. Detail of the medium to fine-grained quartzite found at Sangla Hill.




**C**. Fragment (H98/8590-3) of Kirana stone from Period 1 at Harappa similar in appearance to the Sangla sub-type.



**D**. Kirana Hills outcrops astride the Chenab River at Chiniot, Punjab.



**E**. Detail of the coarse-grained, conglomeritic quartzite found at the Rabwa area outcrops.




**F**. Broken quern (H96/7466-12) from Period 2 at Harappa that looks similar to the Kirana Hills Rabwa sub-type.

level of confidence. In the following sections I use this dataset to investigate how acquisition patterns for this important utilitarian goods shifted as the site was transformed over time from a small village into a large urban center. I also investigate if variations in source utilization existed between the different habitation areas at Harappa during those periods (2 through 3C) from which grindingstones have been recovered from two or more of the site's mounds.

### Site-wise diachronic trends in grindingstone source utilization

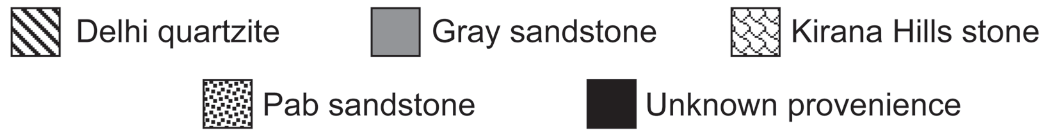
I begin with a presentation of the general diachronic trends in grindingstone source use for the site of Harappa as a whole (without reference to temporal trends on individual mounds). These trends have been calculated in two ways: by number of artifacts by period (Figure 5.27) and by total weight of all artifacts in each category by period (Figure 5.28). I present both methods here because, although they have produced some notably different compositional patterns during certain periods, the basic large-scale diachronic trends appear to be more or less the same using either weight or number for calculating use percentages. We see that the sources in the Kirana Hills are by far the most heavily utilized during the early pre and early urban periods (Ravi and Kot Diji Phases) but then appear to rapidly fall out of use starting in the fully urban period (Harappa Phase). Conversely, Pab sandstone utilization is sparse early on but increases significantly after the beginning of the urban phase. Very little Delhi quartzite is used as grindingstone at first but its overall proportion in the assemblage slowly and steadily increases over time. Gray sandstone seems to have always remained a relatively minor component of the grindingstone assemblage, never reaching 10% of the total during any period at Harappa.

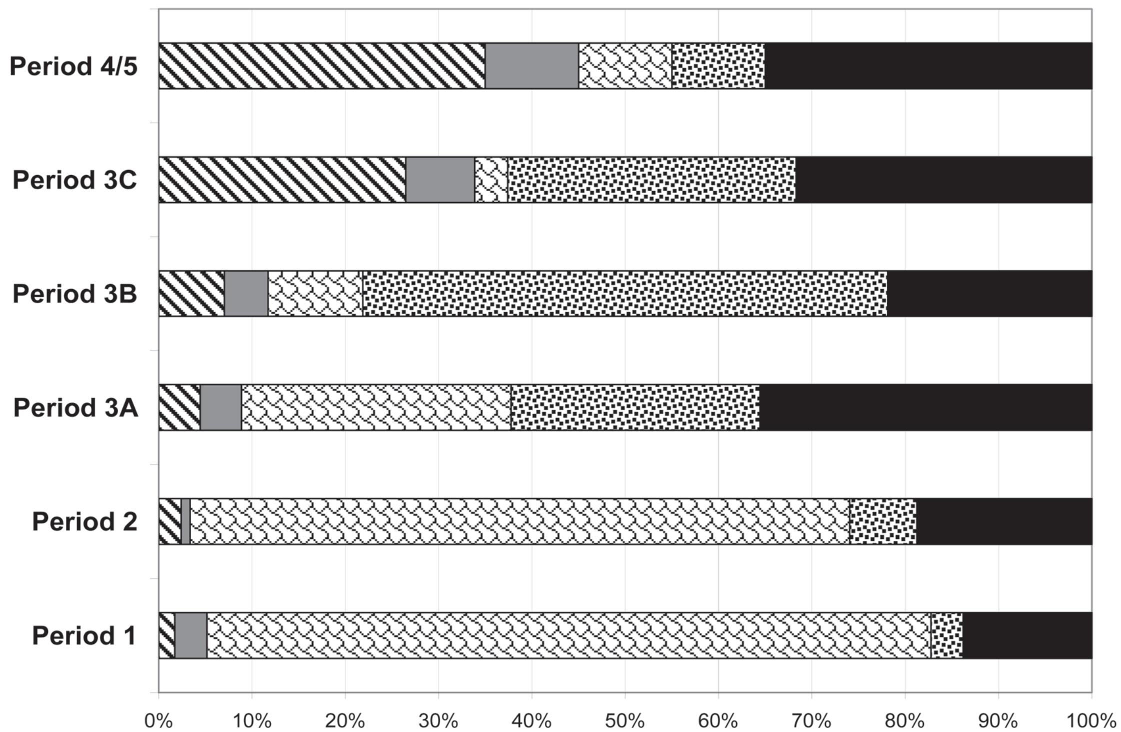
I now examine these trends in detail; phase by phase and mound by mound. I refer to the percentages calculated by total weight listed in Figure 5.27 when discussing site-wise geologic source or material type (source-type) grindingstone use patterns. When looking at differences in material use between habitation areas, I exclude grindingstone artifacts recovered from features of the site outside of the main mounded areas (such as the cemetery area or various Harappan period dumps) from consideration, even though they may be from secure and dateable contexts. All of the remaining percentages that I discuss in this section have been calculated by total weight of each material type and are listed in the accompanying figures.

### Ravi Phase – Period 1 (ca. 3300 BC to 2800 BC)

Although there is evidence of a Ravi Phase occupation in the northwest corner of Mound E (Kenoyer and Meadow 2000), at present, all of the grindingstones from the that period at Harappa (Figure 5.29) come from excavation units in Trench 39 on the northern end of Mound AB. During this initial phase the residents of the then village-size settlement (ibid.) acquired the vast majority (84.5%) of their stone for grinding purposes from the nearest sources in the Kirana Hills. Most of the remaining material (10.7%) recovered from this period is of unknown provenience. Some of these "unknowns" are mafic (dark colored due high magnesium and iron content) rocks like dolerite that could themselves come from the intrusive igneous bodies that also occur at places in the Kirana Hills. A few of examples of Pab sandstone, Delhi quartzite and gray sandstone are present in these early levels also. This indicates that, even at this initial stage, some degree of interaction was taking place with the distant regions to the west and east of Harappa where those material sources are found. By and large, however, it is clear that during Ravi Phase Harappans were very much focused on utilizing the closest and, presumably, most accessible grindingstone sources.

**Figure 5.27**: Grindingstone source utilization through time (percentage calculated by ***number of individual objects***)



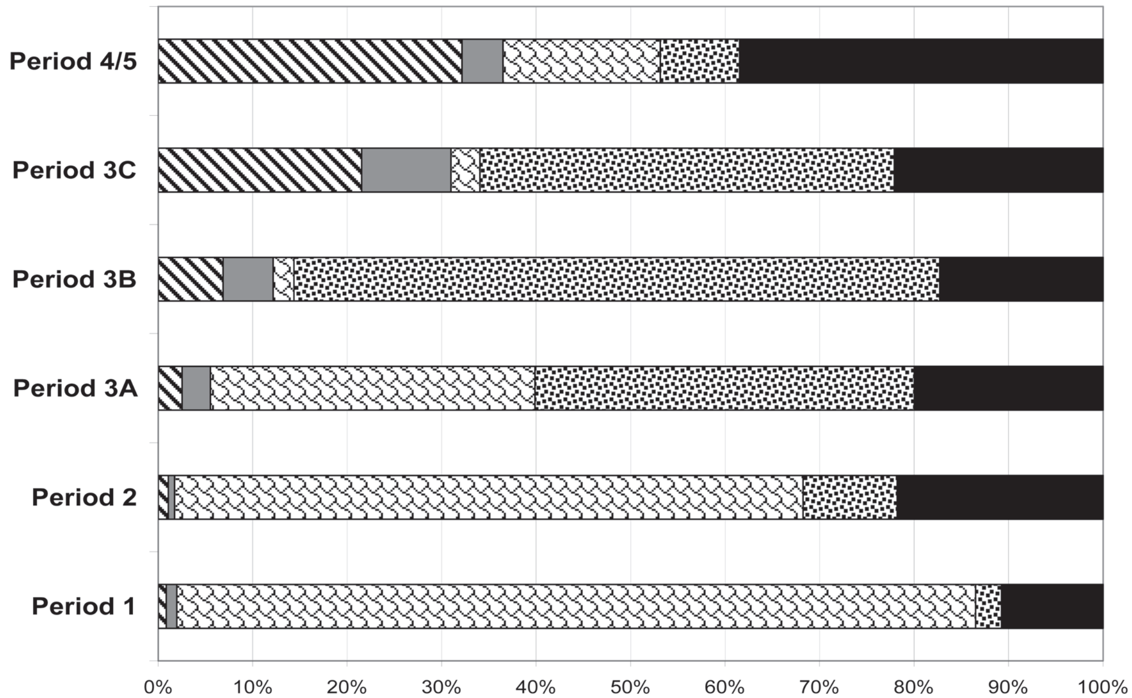

| | Period 1 | *n* = | Period 2 | *n* = | Period 3A | *n* = | Period 3B | *n* = | Period 3C | *n* = | Period 4/5 | *n* = |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Delhi quartzite** | 1.72% | *1* | 2.40% | *5* | 4.44% | *2* | 7.03% | *9* | 26.48% | *269* | 35.00% | *7* |
| **Gray SS** | 3.45% | *2* | 0.96% | *2* | 4.44% | *2* | 4.69% | *6* | 7.38% | *75* | 10.00% | *2* |
| **Kirana Hills stone** | 77.59% | *45* | 70.67% | *147* | 28.89% | *13* | 10.16% | *13* | 3.54% | *36* | 10.00% | *2* |
| **Pab SS** | 3.45% | *2* | 7.21% | *15* | 26.67% | *12* | 56.25% | *72* | 30.91% | *314* | 10.00% | *2* |
| **unknown** | 13.79% | *8* | 18.75% | *39* | 35.56% | *16* | 21.88% | *28* | 31.69% | *322* | 35.00% | *7* |
| *total* | 100% | *58* | 100% | 208 | 100% | *45* | 100% | *128* | 100% | *1016* | 100% | *20* |

## Kot Diji Phase – Period 2 (2800 to 2600 BC)

By the subsequent Kot Diji Phase, the site of Harappa and Harappan society were well on their way to becoming fully urban. The area of settlement grew to encompass all or most of. Mound AB, Mound E and parts Mound ET (Meadow and Kenoyer 2001: 24). In total, 208 grindingstones have been recovered from trenches penetrating Period 2 levels in mounds AB and E (Figure 5.30). Residents of the young

**Figure 5.28**: Grindingstone source utilization through time (percentage calculated by ***total weight*** of each type)




| | **Period 1** percentage (weight) | **Period 2** percentage (weight) | **Period 3A** percentage (weight) | **Period 3B** percentage (weight) | **Period 3C** percentage (weight) | **Period 4/5** percentage (weight) |
|---|---|---|---|---|---|---|
| **Delhi quartzite** | 0.86% (80.2 g) | 1.06% (397.0 g) | 2.5% (313.4 g) | 6.87% (4060 g) | 21.54% (73902 g) | 32.16% (988.5 g) |
| **Gray SS** | 1.12% (104.3 g) | 0.68% (253.4 g) | 3.0% (374 g) | 5.28% (3122.2 g) | 9.45% (32413.7 g) | 4.33% (133.2 g) |
| **Kirana Hills stone** | 84.53% (7890.7 g) | 66.51% (24819 g) | 34.3% (4275.2 g) | 2.22% (1311.6 g) | 3.05% (10471.9 g) | 16.66% (512 g) |
| **Pab SS** | 2.74% (256 g) | 9.95% (3714 g) | 40.1% (4997.1 g) | 68.34% (40378.1 g) | 43.86% (150479.2 g) | 8.37% (257.1 g) |
| **unknown** | 10.75% (1003.7 g) | 21.80% (8133.9 g) | 20.0% (2486.8 g) | 17.29% (10213.4 g) | 22.10% (75817.57 g) | 38.48% (1182.6 g) |
| *total* | 100% (9334.9 g) | 100% (37317.6 g) | 100% (12446.5 g) | 100% (59085.3 g) | 100% (343084.4 g) | 100% (3073.4 g) |

city were now part of the Early Harappan cultural entity termed "Kot Dijian", which extended from central Sindh in the south to the Potwar Plateau in the north (Mughal 1990a). Despite their increasing social complexity and enlarged cultural horizons the majority of the grindingstone Harappans used (66.5%) was still obtained from the closest sources in the Kirana Hills. However, percentages of the other grindingstone types do begin to increase somewhat (Pab sandstone in particular grows to comprise nearly

**Figure 5.29:** Grindingstone source utilization on Mound AB – **Period 1**
(percentage calculated by *total weight* of each type)




| **Mound AB** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 1 | 80.2 | 0.86% |
| Gray sandstone | 2 | 104.3 | 1.12% |
| Kirana Hills stone | 45 | 7890.7 | 84.53% |
| Pab sandstone | 2 | 256 | 2.74% |
| Unknown | 8 | 1003.7 | 10.75% |
| *total* | 58 | 9335 | 100% |

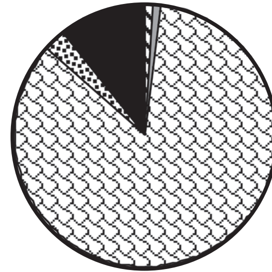
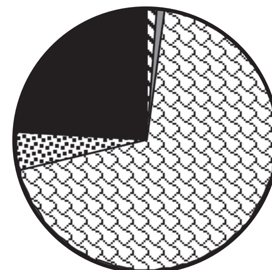


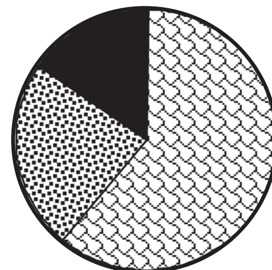
**Figure 5.30:** Grindingstone source utilization by mound – **Period 2**
(percentage calculated by *total weight* of each type)




| **Mound AB** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 4 | 354.2 | 1.33% |
| Gray sandstone | 2 | 253.4 | 0.95% |
| Kirana Hills stone | 82 | 18290 | 68.89% |
| Pab sandstone | 7 | 1204.9 | 4.54% |
| Unknown | 26 | 6447.2 | 24.28% |
| *total* | 121 | 26550 | 100.00% |



| **Mound E** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 1 | 43.1 | 0.40% |
| Gray sandstone | 0 | 0 | 0.00% |
| Kirana Hills stone | 65 | 6529 | 60.63% |
| Pab sandstone | 8 | 2509.1 | 23.30% |
| Unknown | 13 | 1686.7 | 15.66% |
| *total* | 87 | 10768 | 100% |



10% of the Period 2 assemblage) suggesting that some people living at or visiting the site were beginning to expend energy and/or wealth acquiring greater quantities of material from those higher quality but more distant grindingstone sources. Such increases may represent another aspect of the socio-economic development that is evident during this incipient-urban phase (Kenoyer and Meadow 1999).

The percentage of Kirana Hills stone used by Harappans occupying the two main mounds during this period does not seem to have not differed greatly (68.9% for AB vs. 60.6 % for E). Residents of Mound E seem to have used much more Pab sandstone their counterparts on AB (23.3% for E vs. only 4.4 % for AB). People living on AB made up part of that difference by utilizing more Delhi quartzite and gray sandstone (2.2% combined) than their counterparts on Mound E (only a single small fragment of Delhi quartzite and no gray sandstone at all that been recovered thus far from Period 2 level on Mound E).

Overall, it seems that although all residents of Harappa still relied on the closest sources for the majority of their grindingstone requirements during Period 2, they were beginning to acquire a markedly larger portion (nearly one-quarter of the overall total in the case of Mound E) of material from more distant sources. The fact that people residing on Mound E used over 80% more Pab sandstone than people on AB could perhaps indicate that the former group had stronger economic and/or social ties to the region west of Harappa at this time.

## Harappa Phase – Period 3A (2600 to 2450 BC)

Fully urban lifeways at Harappa had emerged by Period 3A, the first of three sub-periods of the Harappa Phase. Unlike other some other Indus sites where there are reported to be sharp demarcations between the Early Harappan and Harappan occupations – such as at Kot Diji (a site-wide episode of burning – Khan 1965) or Ghandi Umar Khan (a 50 cm sterile layer – Ihsan Ali 2004 *personal communication*), the transition between the two periods at Harappa itself is one of "gradual transformation" (Meadow and Kenoyer 2001: 25). Approximately 20 grindingstones came from levels deposited right around the late Period 2 to early 3A transition. The context of each of those artifacts was judged individually and, for analytical purposes, was assigned to either Period 2 or 3A. Even though the majority were placed into the Period 3A group, the number of querns and mullers from this period totals only 45 artifacts, which are more or less even split between excavated 3A levels on Mounds AB and E (Figure 5.31). With the exception of the combined assemblage for periods of 4 and 5, this represents the smallest sample we have for any of the periods under consideration. Even a handful of samples added to any one of the material categories could significantly alter the percentages presented here. I have raised the issue at this point because although the Period 1 grindingstone assemblage was nearly as small (n=58) as this one, the site at that time is thought to have been only been seven to ten hectares in size (Kenoyer and Meadow 2000: 56). By Period 3A, however, Harappa was substantially larger. Thus, for this phase we are dealing with both a smaller sample and a bigger area. For these reasons, the data below for this period should be treated with due caution.

In Period 3A, the use of Kirana Hills stone appears fall to around half of what it was during the Kot Diji Phase. This material still, however, makes up fully one-third (34.3%) of the material used as grindingstone by Harappans at that time. Conversely, the utilization of Pab sandstone sees a four-fold increase over the preceding period (rising to 40.1%) making it, for the first time, the most common type of grindingstone used at Harappa. The portion of Delhi quartzite in the assemblage rises slightly (to 2.5%) while gray sandstone use drops a bit (to 3.0%).

To date, grindingstones have been recovered only from Period 3A levels on mounds AB and E. When

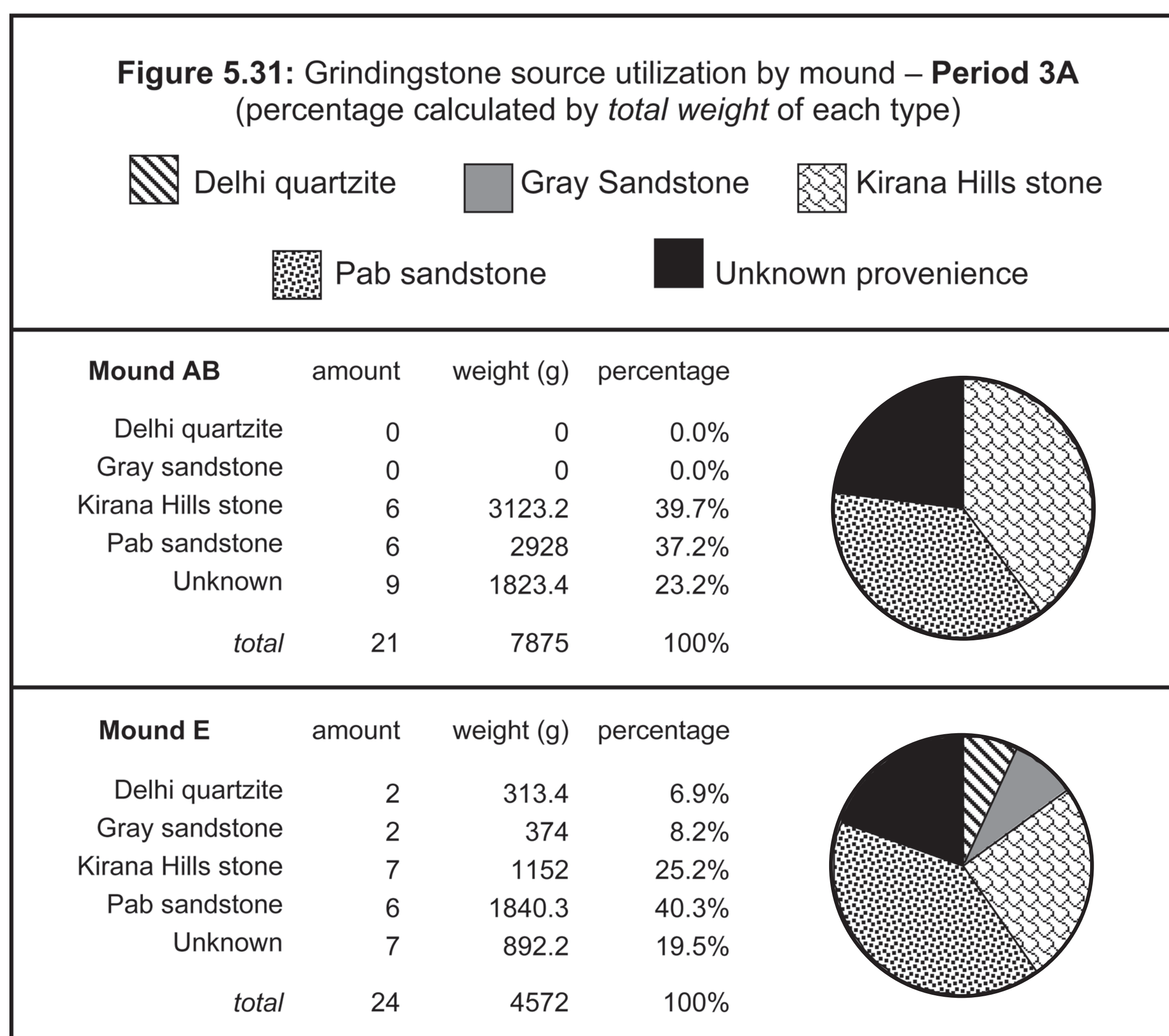


**Figure 5.31:** Grindingstone source utilization by mound – **Period 3A** (percentage calculated by *total weight* of each type)



| Mound AB | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 0 | 0 | 0.0% |
| Gray sandstone | 0 | 0 | 0.0% |
| Kirana Hills stone | 6 | 3123.2 | 39.7% |
| Pab sandstone | 6 | 2928 | 37.2% |
| Unknown | 9 | 1823.4 | 23.2% |
| *total* | 21 | 7875 | 100% |

| Mound E | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 2 | 313.4 | 6.9% |
| Gray sandstone | 2 | 374 | 8.2% |
| Kirana Hills stone | 7 | 1152 | 25.2% |
| Pab sandstone | 6 | 1840.3 | 40.3% |
| Unknown | 7 | 892.2 | 19.5% |
| *total* | 24 | 4572 | 100% |

assemblage compositions on those two habitation areas are compared it is evident that for Pab sandstone there is hardly any disparity in material use between them (40.3% for E vs. only 37.2% for AB). It does appear that Harappans residing on Mound AB tended to use somewhat more (39.7%) Kirana Hills stone than did those dwelling on Mound E (25.2%). People on Mound E, however, made up the difference by utilizing Delhi quartzite and gray sandstone (15.1% combined) while neither of those materials have been recovered thus far from Period 3A level on Mound AB.

In summary, despite the fact that during this initial period of the fully urban phase the percentage of querns and mullers made from Kirana Hills stone falls considerably, these closest rock outcrops to Harappa remained significant sources for grindingstone material. The emphasis, however, had evidently begun to shift toward the acquisition-consumption of higher quality Pab sandstone from more distant sources in the Sulaiman Range. Differences in source utilization between habitational areas at Harappa do not seem to be pronounced during this period. Once again, because of the small sample of grindingstones from Period 3A in combination with the larger size of Harappa at that time levels, these conclusions should be considered tentative.

### Harappa Phase – Period 3B (2450 to 2200 BC)

Approximately three times as many grindingstone samples (n=128) have been recovered from stratified contexts in Period 3B (Figure 5.32) than from the

preceding phase. However, with the addition of querns and mullers recovered from Period 3B levels on mounds F and ET, a greater spatial area is now under consideration. Therefore a degree of caution is once again advised, especially for data from mounds AB and F where only 11 and 7 (respectively) grindingstone artifacts have been recovered for this time period.

Period 3B, which was a time of urban renewal for some Harappans (most notably for those residing on Mound E – Kenoyer 1992a: 6), sees some rather significant shifts in grindingstone source-type utilization at the site. Kirana Hills stone, the dominant material type for the first two periods at Harappa, now accounts for only 2.2% of the overall grindingstone assemblage. It appears instead that Harappans are acquiring nearly 70% of their querns and mullers in the form of Pab sandstone from the Sulaiman Range. Small increases in the use of Delhi quartzite and gray sandstone are once again seen during this period. When assemblage compositions between mounds E and ET (the two habitation areas from which the most samples were recovered) are compared we see that the differences between them are generally slight. Pab sandstone was by far the most-used material for grindingstone on both mounds (76.2% for E vs. only 71.0% for ET) and the three remaining identifiable types collectively account for approximately 10 to 15 percent of the assemblages in both areas. Such similar patterns suggest close ties between the two areas. Although evidence of occupation east of Mound E in the area now defined as Mound ET extends back to the Kot Diji Phase (Meadow and Kenoyer 1997: 140), grindingstones have only been recovered in 3B and later levels on that mound. By that time, Mound ET was encompassed by a perimeter wall (built in late Period 3A or early Period 3B), which extended directly from the city walls of Mound E (ibid.: 143-144) and joined the two habitation areas in a manner suggesting that an expansion of, or annexation by, the larger mound had taken place. If during Period 3B the residents of Mound E exerted a degree of control regarding what raw materials were used by people living and working on Mound ET or if the residents of both mounds were members of the same social-political group, then the closely related source-type use patterns seen for the two areas are understandable.

On mounds AB and F the assemblage compositions appear quite different than those of mounds E and ET. When compared to the overall percentage, Kirana Hills stone accounts for a minor but still significant portion of the grindingstones on both mounds (15.3% for F and 17.3% for AB). Delhi quartzite is the most (45.6%) utilized grindingstone on AB during Period 3B while Pab sandstone use falls far below site-wise average at only 7.88%. On Mound F only two of the identifiable types of querns and mullers appear to have been used. Pab sandstone makes up just over half of the assemblage while Kirana Hills stone (mentioned above) accounts for a smaller portion.

In summarizing this period it is worth again emphasizing that the grindingstone assemblages from Period 3B levels on Mounds AB and F are extremely small. Even so, the differences in assemblage source-type composition between mound group E-ET and AB (and to a lesser degree Mound F) may actually have some basis in the reality of grindingstone acquisition behavior during this sub-phase. As mentioned above, Period 3B was a time of rebuilding and renewal on Mound E and perhaps ET. It is conceivable then that at this time residents in these areas of the site were generally more affluent than their fellow Harappans residing on mounds AB and F and so could afford to expend more wealth obtaining high quality Pab sandstone. On the other hand, it may indicate that the people of mounds E and ET had stronger social-economic times with the groups in the Sulaiman region than did those dwelling on the other mounds – a situation similar to the one that perhaps also existed for Mound E during the Kot Diji Phase.

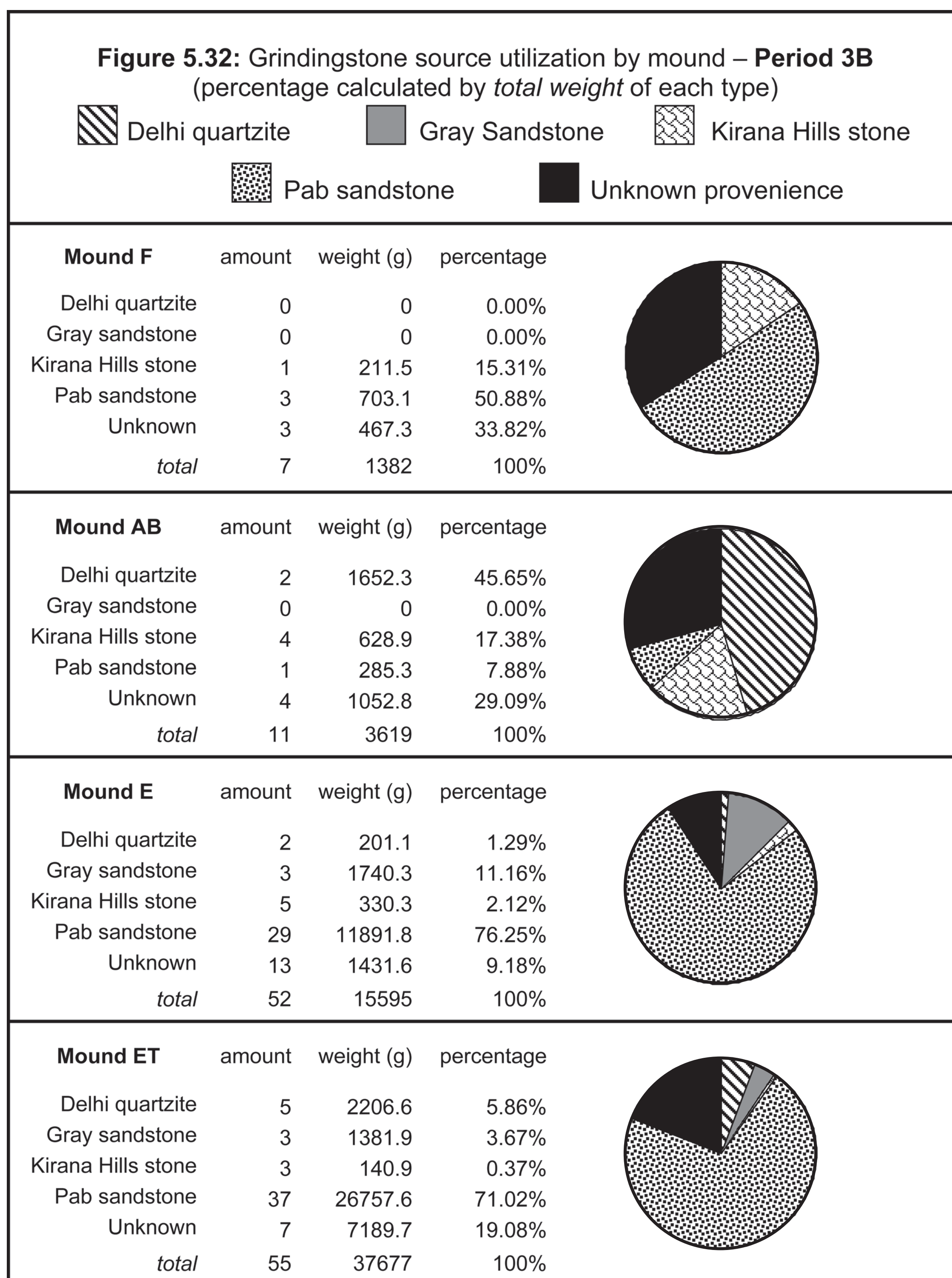



**Figure 5.32:** Grindingstone source utilization by mound – **Period 3B** (percentage calculated by *total weight* of each type)

| **Mound F** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 0 | 0 | 0.00% |
| Gray sandstone | 0 | 0 | 0.00% |
| Kirana Hills stone | 1 | 211.5 | 15.31% |
| Pab sandstone | 3 | 703.1 | 50.88% |
| Unknown | 3 | 467.3 | 33.82% |
| *total* | 7 | 1382 | 100% |

| **Mound AB** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 2 | 1652.3 | 45.65% |
| Gray sandstone | 0 | 0 | 0.00% |
| Kirana Hills stone | 4 | 628.9 | 17.38% |
| Pab sandstone | 1 | 285.3 | 7.88% |
| Unknown | 4 | 1052.8 | 29.09% |
| *total* | 11 | 3619 | 100% |

| **Mound E** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 2 | 201.1 | 1.29% |
| Gray sandstone | 3 | 1740.3 | 11.16% |
| Kirana Hills stone | 5 | 330.3 | 2.12% |
| Pab sandstone | 29 | 11891.8 | 76.25% |
| Unknown | 13 | 1431.6 | 9.18% |
| *total* | 52 | 15595 | 100% |

| **Mound ET** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 5 | 2206.6 | 5.86% |
| Gray sandstone | 3 | 1381.9 | 3.67% |
| Kirana Hills stone | 3 | 140.9 | 0.37% |
| Pab sandstone | 37 | 26757.6 | 71.02% |
| Unknown | 7 | 7189.7 | 19.08% |
| *total* | 55 | 37677 | 100% |

Or (quite possibly) the very small sample sizes for mounds AB and F may have resulted in an inaccurate representation of the true source-type composition for those areas. Whatever the case may be, overall this period does see the continuation of trends that had been developing since the early phases – namely, increasingly steeper declines in the use of Kirana Hills stone over time, progressively greater use Pab sandstone and a slow but steady increase overall of Delhi quartzite utilization.

### Harappa Phase – Period 3C (2200 to 1900 BC) and surface/disturbed context finds

Harappa's grindingstone assemblage from Period 3C is the most robust of the entire sequence, consisting of over 1000 artifacts. Examples have been recovered in nearly every trench across the site in which Period 3C deposits have been exposed, which is to say nearly every trench across the site. Thus, appraisals of grindingstone source-type usage between habitation areas made for Period 3C are the most statistically secure and spatially representative of any chronological phase.

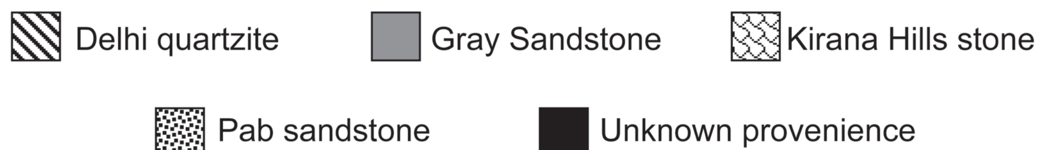
Looking at the overall source-type use pattern for Period 3C, we see that Pab sandstone is again the most utilized material for grindingstone at Harappa, although its percentage in the assemblage decreases to around 44% from its high of nearly 70% during the preceding period. Some of that decrease may be due to concurrent increases in the utilization of Delhi quartzite, which jumps markedly to 21.5% of the total, and gray sandstone, which sees its highest percentage (9.5%) in the entire chronological sequence. Apparently, Kirana Hills stone was infrequently used for grinding purposes during Period 3C, accounting for just 3% of the recovered assemblage.

Turning now to source-type usage between Harappa's mounds during Period 3C (Figure 5.33), we once again observe that the grindingstone use patterns for mounds E and ET are remarkably similar. Pab sandstone was the most utilized material for querns and mullers on E and ET– ranging from 52% to 57% of the assemblages. Delhi quartzite was used approximately 20% of the time, gray sandstone 8% and Kirana Hills stone less than 3% on both mounds. The continuation from Period 3B of roughly parallel assemblage compositions provides additional evidence that may indicate that factors determining grindingstone usage (be they economic or social-political) were the same for residents on both mounds E and ET.

Over on mounds AB and F, we again see in this period that the patterns of use in those areas were quite different that those on E-ET. On Mound F, Delhi quartzite made up around half (44.7%) of the grindingstones used (twice as much as in any other area), Pab sandstone use was approximately one-third (15%) of the site average of 43.8% and the utilization of gray sandstone and Kirana Hills stone was roughly same as the site averages for those materials. On Mound AB, Pab sandstone made up one-third (33.1%) of the assemblage while another one-third were more or less evenly divided between the other three identifiable grindingstone types. Also in contrast to mounds E-ET, the assemblage compositions on both mounds AB and F for Period 3C differ greatly from than the ones for those same areas during the preceding period. This perhaps indicates that the factors (local and/or external to Harappa) influencing resource acquisition for residents of those mounds were somehow in flux between periods 3B and 3C. However, I would point out yet again that the perceived diachronic differences could be misleading due to the small sample sizes for Periods 3B assemblages on AB and F.

It useful at this point to examine the mound by mound grindingstone assemblage composition data for artifacts recovered during surface surveys and from disturbed contexts such as brick robber trenches (Figure 5.34). A comparison of the pie-charts in figures 5.13 and 5.14 shows that the patterns of the surface-disturbed assemblages closely mirror, in most cases, those of Period 3C assemblages from their respective mounds. I suggest here that those patterns help substantiate the grindingstone usage patterns that have been defined for Harappa's individual mounds during Period 3C. It is of course true that querns and mullers found in such non-secure contexts could be from any chronological phase (even historic or modern). However, the brick robbing of the mid-19th century effectively removed nearly all of the upper levels of the site resulting in the exposure of mostly Period 3C deposits across Harappa's surface. It

**Figure 5.33:** Grindingstone source utilization by mound – **Period 3C**
(percentage calculated by *total weight* of each type)




| **Mound F** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 49 | 21120 | 44.7% |
| Gray sandstone | 10 | 4347 | 9.2% |
| Kirana Hills stone | 6 | 946 | 2.0% |
| Pab sandstone | 17 | 7090 | 15.0% |
| Unknown | 54 | 13742 | 29.1% |
| *total* | 136 | 47245 | 100% |

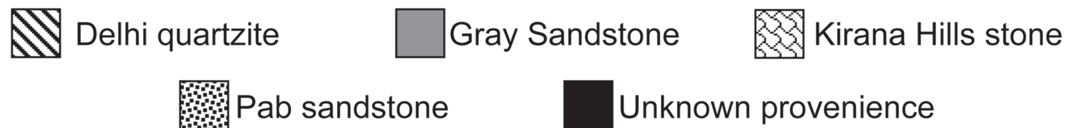
| **Mound AB** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 21 | 6357 | 14.78% |
| Gray sandstone | 10 | 3383 | 7.86% |
| Kirana Hills stone | 8 | 4272 | 9.93% |
| Pab sandstone | 24 | 14261 | 33.14% |
| Unknown | 34 | 14932 | 34.71% |
| *total* | 97 | 43205 | 100% |

| **Mound E** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 96 | 25180 | 17.35% |
| Gray sandstone | 22 | 12853 | 8.86% |
| Kirana Hills stone | 10 | 3911 | 2.69% |
| Pab sandstone | 159 | 75906 | 52.31% |
| Unknown | 117 | 27268 | 18.79% |
| *total* | 404 | 145117 | 100% |

| **Mound ET** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 73 | 16202 | 22.55% |
| Gray sandstone | 20 | 5824 | 8.10% |
| Kirana Hills stone | 11 | 947 | 1.32% |
| Pab sandstone | 85 | 40976 | 57.02% |
| Unknown | 51 | 7914 | 11.01% |
| *total* | 240 | 71862 | 100% |

is probable that many (perhaps even a large majority) of querns and mullers recovered from the present-day surface of the site (or in brick robber trench fill that derived from the surface or higher levels) come from that occupational phase. In addition, every meter of the site's surface has been surveyed by the HARP at one time or another resulting in a substantial collection of grindingstones representing each of the major mounds (n = 917 total). Although it's true that unstratified or redeposited artifacts such as these

**Figure 5.34:** Grindingstone source utilization by mound –
**Surface and disturbed contexts**
(percentage calculated by *total weight* of each type)




| **Mound F** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 25 | 23319 | 48.12% |
| Gray sandstone | 6 | 3387 | 6.99% |
| Kirana Hills stone | 4 | 485 | 1.00% |
| Pab sandstone | 17 | 9464 | 19.53% |
| Unknown | 34 | 11807 | 24.36% |
| *total* | 86 | 48462 | 100% |

| **Mound AB** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 26 | 5532 | 10.99% |
| Gray sandstone | 9 | 3300 | 6.55% |
| Kirana Hills stone | 31 | 5913 | 11.74% |
| Pab sandstone | 31 | 9026 | 17.92% |
| Unknown | 90 | 26589 | 52.80% |
| *total* | 187 | 50360 | 100% |

| **Mound E** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 116 | 24177 | 17.88% |
| Gray sandstone | 14 | 4218 | 3.12% |
| Kirana Hills stone | 21 | 7975 | 5.90% |
| Pab sandstone | 197 | 68947 | 51.00% |
| Unknown | 133 | 29883 | 22.10% |
| *total* | 481 | 135201 | 100% |

| **Mound ET** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 47 | 12840 | 29.84% |
| Gray sandstone | 12 | 2089 | 4.85% |
| Kirana Hills stone | 2 | 508 | 1.18% |
| Pab sandstone | 61 | 19248 | 44.73% |
| Unknown | 41 | 8347 | 19.40% |
| *total* | 163 | 43032 | 100% |

may have been moved far from their original points of deposition, it is highly unlikely that a substantial number of them (if any) came from a mound other than the one on which they were found. In other words, a quern recovered from the surface of Mound AB was almost certainly used by the former residents of Mound AB. For these reasons I would argue that, as long as its potential limitations are recognized, the similar source-type composition of the surface-disturbed assemblage provides a good line of

**Figure 5.35:** Grindingstone source utilization on Mound AB – **Periods 4/5**
(percentage calculated by *total weight* of each type)




| **Mound AB** | amount | weight (g) | percentage |
|---|---|---|---|
| Delhi quartzite | 7 | 988.5 | 32.16% |
| Gray sandstone | 2 | 133.2 | 4.33% |
| Kirana Hills stone | 2 | 512 | 16.66% |
| Pab sandstone | 2 | 257.1 | 8.37% |
| Unknown | 7 | 1182.6 | 38.48% |
| *total* | 20 | 3073 | 100% |

supporting evidence for the patterns of grindingstone use at Harappa during Period 3C and later phases.

In summary, although Pab sandstone remained the most commonly used material for querns and mullers at the Harappa during Period 3C, Delhi quartzite was being brought to the site in much higher quantities than before, suggesting that long-distance trade to regions east of the site was intensifying during this period. Residents of Mound F appear to be the ones most actively involved in these eastern grindingstone acquisition networks as they consumed twice as much as the site-wise average for Delhi quartzite. Gray sandstone and, in particular, Kirana Hills stone, were used in only small amounts overall. However, even though the assemblage composition on Mound AB is fairly mixed, people living there did use three times the site-wise average for Kirana Hills stone. In fact, residents of AB had been the highest users of Kirana Hills stone for every phase going back to Period 2. Those who lived on mounds E and ET continued to exhibit patterns of grindingstone source-type usage similar to each other. Although still relying mostly on Pab sandstone, they too were using an increasingly greater amount of Delhi quartzite.

### Transitional and Late Harappa Phase – Periods 4 & 5 (ca. 1900 to <1300 BC)

Due to the fact that intact post-Period 3C deposits are rare at Harappa, the total number of querns and mullers recovered from the Harappa to Late Harappa Transitional Phase (Period 4) and Late Harappa Phase (Period 5) is small (n=20). Artifacts from these periods are therefore considered as a single assemblage. Also, although there is evidence that Late Harappa occupations existed on Mounds F and E-ET, all of the grindingstones from those phases come from a single trench (Tr. 38) on the north side of Mound AB. It should be kept in mind, then, that the usage pattern for this small part of Mound AB may not be at all representative of what was occurring elsewhere on the site, especially since this was often the case in other periods (notably 3B and 3C).

Despite the apparent cessation of important long-distance interaction networks with Sindh and Gujarat during the later periods at Harappa, several lines of evidence (demographic, paleoethnobotanical, technological) suggests that activity and innovation continued at Harappa itself (Kenoyer 2005b). Interesting new patterns also appear to have been taking place during these late occupational phases in

terms of grindingstone acquisition (Figure 5.35). Both Delhi quartzite (32.2%) and "unknown" grindingstone types (38.5.7%) reach their highest percentages for any chronological phase. Delhi quartzite was, for the first time, more frequently used than Pab sandstone, which now accounts for fewer than 10% of the artifacts in the assemblage. In addition, Kirana Hills stone was used twice as often as Pab sandstone while utilization of gray sandstone dropped by half over Period 3C.

The changes in material source-type usage seen on Mound AB may reflect the general demographic shift of Harappan peoples toward the eastern Punjab and the western Gangetic region that occurred during the Late Harappan Periods (Possehl 1997c). As the emphasis on trade and interaction shifted eastward, Delhi quartzite source would have been even more accessible through interaction with the Late Harappans of Haryana. Access to new sources of grindingstone from around the Gangetic region could account for the increase in "unknown" types. The dramatic drop in Pab sandstone use may indicate that contacts with areas to the west of Harappa had decreased in intensity or at least that the nature of the interaction networks shifted away from the supply of bulk goods. A slightly greater reliance on closer sources for utilization materials during this period is suggested by the small increase in the presence of Kirana Hills stone in the assemblage.

## DISCUSSION: PATTERNS OF GRINDINGSTONE ACQUISITION AND DISCARD AT HARAPPA

Residents of Harappa acquired the majority of the stone that they used for processing cereals and other grinding purposes from one of four regions. From the Sulaiman Mountains they acquired Pab sandstone. The type of Delhi quartzite Harappans used seems to have been brought from a fairly restricted area (Kaliana Hills) of southern Haryana. The gray sandstone querns and mullers found at the site probably were acquired as water-worn cobbles from the Lower Himalayas or Siwaliks foothills. Finally, it appears that two different types of stone from the (relatively) nearby Kirana Hills were used. The presence of each of these types of stone at Harappa provides unambiguous evidence that some form of interaction (either direct or indirect) existed between the site and the regions from which they originated. In forthcoming chapters, I demonstrate that numerous varieties of stone and metal found at Harappa came from the Salt Range or regions beyond it. Somewhat conspicuous in its absence, then, is stone from those mountains such as Khewra sandstone. It would almost certainly be identifiable in the site's grindingstone assemblage if it were present. In any case, this geologic provenience study of querns and mullers demonstrates that residents of Harappa of all phases participated in exchange networks for utilitarian goods that extended across an area of no less than 600 km from west to east.

Examples of all four of the identifiable grindingstone types are present in each phase at Harappa. The proportions of those types that make up each chronological sub-assemblage, however, vary significantly from phase to phase. The most striking change in grindingstone source-type usage is the shift in emphasis over time toward the acquisition of stone from sources between 225 and 400 km away from the site. For approximately 1000 years following the initial settlement of Harappa, the large majority (≈ 85%) of mullers and querns were brought to the site from the closest possible sources in the Kirana Hills, which were only 120 km away. A trend toward the acquisition of stone from the more distant sources begins in the proto-urban phase (Period 2) and culminates in the middle of the urban phase (Period 3B) when only 2% of grindingstones used there came from the Kirana Hills region.

Why, over time, would residents of Harappa

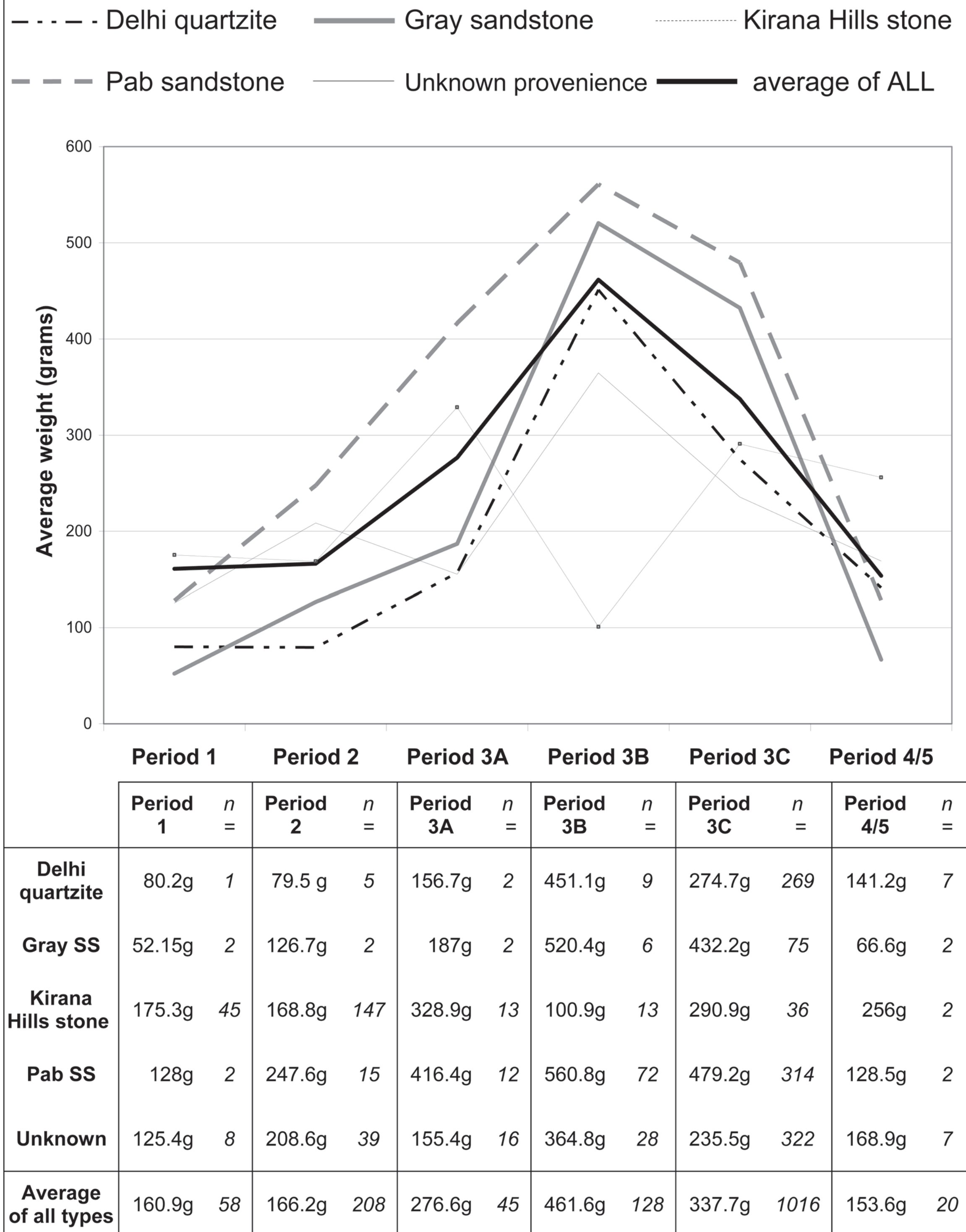



**Figure 5.36**: Average weights of grindingstones (whole and fragmentary) by period.

| | Period 1 | n = | Period 2 | n = | Period 3A | n = | Period 3B | n = | Period 3C | n = | Period 4/5 | n = |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delhi quartzite | 80.2g | 1 | 79.5 g | 5 | 156.7g | 2 | 451.1g | 9 | 274.7g | 269 | 141.2g | 7 |
| Gray SS | 52.15g | 2 | 126.7g | 2 | 187g | 2 | 520.4g | 6 | 432.2g | 75 | 66.6g | 2 |
| Kirana Hills stone | 175.3g | 45 | 168.8g | 147 | 328.9g | 13 | 100.9g | 13 | 290.9g | 36 | 256g | 2 |
| Pab SS | 128g | 2 | 247.6g | 15 | 416.4g | 12 | 560.8g | 72 | 479.2g | 314 | 128.5g | 2 |
| Unknown | 125.4g | 8 | 208.6g | 39 | 155.4g | 16 | 364.8g | 28 | 235.5g | 322 | 168.9g | 7 |
| Average of all types | 160.9g | 58 | 166.2g | 208 | 276.6g | 45 | 461.6g | 128 | 337.7g | 1016 | 153.6g | 20 |

increasingly acquire their grindingstones from comparatively distant sources when much closer ones were at hand? Doing so would surely have required them to expend a greater amount of energy and/ or wealth. The loss or establishment of interaction networks to source regions does not provide a satisfactory answer to the question. As discussed above, Early Harappan period sites are found in the areas where the more distant grindingstone sources are located (at the base of the Sulaiman Range and in southern Haryana) and Harappan period settlements are found in the vicinity of the Kirana Hills. I would

argue that the answer probably has to do with factors relating to qualities of material from different sources in combination with innovations that accompanied the emergence of urban lifeways in the greater Indus region.

Because of their homogeneity, grain size and toughness, Pab Sandstone, Kaliana-type Delhi quartzite and fine gray sandstone are, as compared to the stone available in the Kirana Hills, superior materials for grinding purposes. As just noted, impediments to acquiring those higher quality material types during the Ravi and Kot Diji phases at Harappa probably did not stem from a lack of access to the regions in which they occurred. It is more likely that transportation technologies and infrastructure in the upper Indus Basin during the Early Harappan Phase had not yet developed to the point where moving heavy stone implements overland in large quantities was cost-effective. Transporting heavy loads of stone from the Kirana Hills to Harappa and other sites in the central Punjab could have been easily accomplished by moving them a large portion of the way via watercraft downstream on the southeasterly flowing rivers of the region. The most direct routes from grindingstone sources in the Sulaiman Range and southern Haryana, on the other hand, run mostly perpendicular to those waterways. The transportation of Pab sandstone or Kaliana-type Delhi quartzite to Harappa would have, therefore, had to have taken place mainly via overland routes and on watercraft traveling upstream. As a result, the best quality querns and mullers would have been comparatively more costly to acquire in terms of wealth and/or energy expended.

Transporting heavy loads of stone by land would have been most effectively undertaken using a bullock-pulled two-wheeled cart – an innovation the origins of which are documented at Harappa and other Indus Civilization sites during the fourth and third millennia BC (Kenoyer 2004). Although there is limited evidence of its existence during the Ravi Phase at Harappa, use of the bullock cart increases during the Kot Diji Phase, which incidentally is also the time we see the initial small increase in Pab sandstone in the grindingstone assemblage. Evidence for widespread use of carts across the Greater Indus region and beyond is seen during the Harappa Phase (ibid.). It is during that time, of course, that grindingstones transported from relatively distant sources are the most utilized at Harappa.

Wheeled vehicles traveling across the plains of the Indus Basin would have required some kind of infrastructure in the form of roads or, at the very least, a clear trail. Although no such roadways from this period have yet been discovered, the well-planned streets and broad avenues of Indus towns and cities allow us to reasonably assume that some form of maintained route probably existed in the countryside between Indus settlements. So, with the development of new transportation technologies (documented) and infrastructure (inferred) it became easier to supply Harappa with grindingstones from multiple sources around the upper Indus Basin. As a wider range of materials for querns and mullers became easier to get, many residents of the site chose to utilize the stone of better quality.

The shift toward more distant grindingstone sources could also reflect the general economic prosperity of urban phase Harappans. Residents of an increasingly urbanized settlement, in contrast to their village-dwelling ancestors, might have had comparatively more accumulated wealth to expend on the acquisition and transport of higher quality utilitarian necessities. Without the benefit of readable texts it is difficult to know precisely what value Harappans may have placed on any material. However, it may be instructive to consider changes in the average weight of the grindingstone artifacts during different periods. Less than 5% of the querns and mullers from Harappa have been found in a complete or nearly complete state. It appears that Harappans used these implements until they broke

and then continued to re-use the pieces until at some point they were judged to be too small to be effective. By looking at the average weights for grindingstone artifacts it is possible to get an idea of how small that point was from period to period and from that, a relative sense of how willing Harappan were to discard grindingstone material at different points in time.

Figure 5.36 is a line graph plotting the average weights of individual material types through time at Harappa. Although average weights vary from type to type, most follow a similar trend. This trend is clearly evident when the average weights of all types in a single chronological assemblage are calculated and plotted period by period (bold black line). The general trend is as follows: During both periods 1 and 2 the average weight of discarded grindingstones hovered around 160 g. In the early part of the urban phase (Period 3A) the fragments thrown away were over 100 grams heavier on average than in the previous phases. By Period 3B the average quern or muller discarded by a resident of Harappa was nearly half a kilogram in weight. In the later part of the Harappa Phase (Period 3C) fragments of grindingstones deemed unusable were somewhat smaller (average 365 g) than before. Finally, it appears that Late Harappans (Period 4/5) tended to discard used grindingstones of a weight (153.6 g) that was slightly lower on average than in periods 1 and 2.

How valid are these trends base on average weight? It could be argued that there were factors affecting the average weights of grindingstone artifact assemblages other than, or in addition to, the point at which Harappans of different phases were choosing to throw their querns and mullers away. Any number of post-depositional processes may have acted upon these implements. Also the properties of the different material types themselves may have affected their weights. I have argued that one of the reasons that Kirana Hills stone. was of poorer quality and therefore less preferred over other types is because it is more friable and, thus, more apt to break during use. Should we expect to find many more small pieces of this type as compared to the others? Perhaps not, because it is only in Period 3B that Kirana Hills stone has the smallest average weight of all types. Nor does it appear that varying assemblage sizes from phase to phase is a factor. That is, the trend evident in Figure 5.36 appears to be independent of total number of samples considered in each phase. I would argue these average weights are reasonably good indicators of how the point at which Harappans decided it was worth discarding (and presumably replacing) grindingstone changed from phase to phase. Pab sandstone and Kirana Hills stone both would have been discarded when they more or less reached the same weights. Higher quality Pab sandstone, however, would have lasted longer before reaching that point.

The overall trend evident in Figure 5.36 would make it appear that Early Harappans (periods 1 and 2) were more inclined than their urbanized counterparts in Period 3 to use and re-use broken grindingstone fragments until they were very small. This suggests that such stone was dearer to them than it was to urban phase Harappans. That is, it was probably less readily available and/or more costly to acquire. During Period 3 it seems Harappans were more apt to discard larger pieces of grindingstones despite the fact that the majority used at that time tended to be composed of higher quality materials from distant sources. This suggests that grindingstone during Period 3 generally was not as valuable as it was during Periods 1 and 2 and/or that a reliable supply of comparatively inexpensive material was available to replace broken implements. Interestingly, it is in Period 3B that both the highest proportions of stone from sources over 200 km distant are found in Harappa's grindingstone assemblage and that the heaviest fragments are being discarded. It could be said that during Period 3B, more than in any other period, high quality querns and mullers were plentiful (there were a higher proportion of them) and cheap (they were more readily discarded). The slight drop

in the average weight of grindingstones discarded by Period 3C Harappans may reflect a situation where the amounts of new grindingstone being brought to Harappa through regional trade networks was declining. A deterioration of architectural quality and the maintenance of public thoroughfares suggest that civic authority at Harappa was beginning to wane during that period (Kenoyer 1992a: 6). The steep decline in the average weight of discarded grindingstones that is evident in the Late Harappa Period (4/5) may then indicate that some of those networks had further or failed entirely.

Turning now to intra-site variation in grindingstone source usage, the only phases for which it is possible to compare patterns between two or more habitation areas at Harappa are periods 2 through 3C. In several instances the assemblages recovered from particular mounds are very small (n < 25). This may have resulted in unrepresentative or biased source-type usage patterns. However, even when the possible shortcomings of certain aspects of the dataset are taken into account, there appears to have been some genuine synchronic variation among the habitation areas at Harappa.

Looking first at intra-site similarities we see that all four of the identifiable grindingstones types were used to some degree or another by residents of each of Harappa's habitation areas. Occasionally grindingstone types are missing from some mound assemblages during certain periods but that is probably due, in large part, to problems related to small sample size rather than absence of a material type. It would seem safe to say that all Harappans, regardless of what part of the city they lived in, would have had access to any of the four material types if they wished to acquire them.

Residents of Mounds E and ET left behind more or less parallel patterns of grindingstone source-type usage during both Period 3B and Period 3C. The surface and disturbed context assemblages from the two mounds were also alike in composition. This indicates that people living in both areas had very similar needs, preferences and/or opportunities when it came to choosing grindingstone material. Mound ET has been described as a "suburb" of Mound E (Kenoyer 1998: 55) that was eventually incorporated into it around Period 3B (Meadow and Kenoyer 1997: 140). These findings provide evidence that could be used to support an argument suggesting that residents of the two habitation areas were probably part of the same socio-political entity.

When looking at differences among habitation areas at Harappa we see that residents of Mound E (and eventually E-ET) always seemed to have been the heaviest consumers of Pab sandstone. Only in Period 2 did people of Mound AB use roughly the same amount of that material type. There are several possible explanations for this emphasis on Pab sandstone on mounds E-ET. One is that the peoples living there had the strongest economic and/or social ties to the trans-Indus regions adjacent to the Sulaiman Mountains such as Derajat and the Gomal Plain. It might also be the case that, of all the groups at Harappa, those on E-ET could best afford to expend wealth or energy acquiring high quality Pab sandstone. Or, perhaps, residents of the two joined mounds were engaging (at least more so than Harappans in other parts of the city) in types of craft production or other activities where Pab sandstone was required or particularly well-suited.

Overall, Harappans living and working on the other mounds used significantly less Pab sandstone – approximately one-third on Mound AB and two-thirds less on Mound F in Period 3C. Residents of Mound AB always seemed to have used an above average amount of Kirana Hills stone, even during periods 3B and 3C when that type was least utilized overall in the city. This may indicate that Harappans dwelling in that particular area, which was one of the oldest parts of the city, had the closest "local ties," as it were, to peoples in the northern part of the Punjab Plain. On the other hand, they might have

had slightly less wealth than their contemporaries on other mounds to expend on higher quality types of grindingstone. Or maybe they simply did not engage heavily in activities that required grindingstones with the unique qualities of Pab sandstone.

On Mound F during Period 3C, which is the one phase in that part of the site for which there is a reasonably large grindingstone assemblage to consider, we see that residents there used twice as much Delhi quartzite as anyone else in the city (Mound F's assemblage from surface and disturbed contexts more or less parallels this pattern). This may indicate that, of all Harappa's residents, those in this part of the site had the strongest trade relationships with peoples to the east of Harappa. I later present results from a provenience study of steatite artifacts (Chapter 7) that seem to support this interpretation.

## BRIEF REMARKS ON GRINDINGSTONE ACQUISITION PATTERNS AT OTHER INDUS CITIES

I am currently conducting formal examinations of the grindingstone assemblages from the Indus cities of Dholavira in Gujarat and Rakhigarhi in Haryana. I have also had the opportunity to briefly study collections and/or make surface observations of grindingstones from the sites of Mohenjo-Daro in Sindh and Ganweriwala in Cholistan. Here I would like to make a few short remarks on the acquisition patterns that I see emerging at those cities and how they compare to and, in some cases, fit into the overall pattern seen at Harappa.

Some 90% of the querns and mullers that I have recorded thus far from the Indus city of Rakhigarhi appear to be composed of Delhi quartzite coming from the Kiliana Hills area outcrops, some 75 km to the south. Most of the remain grindingstone from that site is gray sandstone that is likely from the foothill formations or riverbeds of the Lower Himalayas. A handful of Pab sandstone querns and few fragments of what appears to be spotted red Mathura sandstone from the southwestern Gangetic Basin region were also found in the assemblage. The basic acquisition pattern for Rakhigarhi, however, seems to be one that is overwhelmingly focused on the closest regional grindingstone source. When my study of the assemblage is complete, I expect that this pattern will be more or less the same for all periods at the city. It probably will hold true in the larger surrounding region as well. Kiliana Hills Delhi quartzite was by far the most encountered stone at all of the smaller Early Harappan and Harappan sites I visited in Haryana. The difference between the acquisition patterns in this region and those seen at Harappa in the Punjab probably has a lot to due with the quality of material from the closest sources. Excellent quality grindingstone was available from the Kiliana Hills and so there was little need/incentive for regional consumers to seek material from more distant source. On the other hand, stone from the Kirana Hills in the Punjab was of comparatively poor quality. Residents of Harappa largely stopped using that material when it became cost effective to import high-quality grindingstones from distant sources, including the ones 450 km to the east that were preferred by the Indus peoples of Haryana.

The acquisition of grindingstone material from regionally available sources is even more pronounced at Dholavira in Gujarat. No examples Pab sandstone or Kaliana Hills Delhi quartzite have been recorded at that site. All of the querns and mullers that I have examined thus far appear to have come from local rock formations in eastern Kutch or slightly further afield (≈ 150 km) in northern Saurashtra (Dhrangadhra stone).

Like Harappa, the grindingstone assemblages of Mohenjo-Daro and Ganweriwala are much more diverse. Also like Harappa, the most common quern and muller material overall appears to be Pab sandstone, which would have come from

either the Sulaiman Range or, perhaps more likely in the case of Mohenjo-Daro, the Pab sandstone formations of southern Balochistan. I have not yet seen any examples of Kaliana Hills Delhi quartzite at either site. Instead, I encountered many more grindingstones composed of raw material types that were unknown to me. This probably indicates that residents of these cities were accessing stone in areas that I have not yet fully documented, such as the Kirthar Range of Sindh or the Dera Bugti area of Balochistan.

## CHAPTER CONCLUSION

The heavy and unwieldy nature of grindingstones makes examining artifacts in this category especially useful for detecting changes in the ability of ancient peoples to acquire stone resources that were difficult to transport. The large-scale study presented in this chapter revealed that residents of Harappa shifted away from the use of poorer quality grindingstone from the closest available sources during the pre and early urban phases towards the acquisition of higher quality stone from distant sources during the urban phase. I infer that this shift was, in part, due to a marked increase in the capability of Indus Civilization peoples to transport bulk stone goods over long-distances. It may also indicate that high-quality grindingstones had become less expensive during Period 3 and/or that site residents had comparatively more wealth to expend on their acquisition.

In Chapter 13, the results of the grindingstone analysis and their implications are considered again in relation to the other geologic provenience data produced for this study. In the next chapter, I examine the acquisition and use of chert at Harappa and other Indus Civilization settlements. Chert, like grindingstone, was a vital utilitarian material that was acquired by residents of Harappa in large quantities.

# CHAPTER 6

# CHERT ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: THE THREE MAIN TYPES OF CHERT AT HARAPPA

Indus Civilization peoples, although heavy consumers of copper and skilled producers of copper-alloy implements, still chose to utilize chert to manufacture many of the tools (blades, drills, scrapers, awls, etc.) that they used in their daily lives. At Harappa, tools composed of this opaque variety of microcrystalline silicate (or, more commonly, the debris from the manufacture of them) make up more than one-third (37.21%) of the over 56,000 artifacts in the site's rock and mineral assemblage (recall Figure 4.2). Chert also seems to have been the preferred stone for making the distinctively Harappan style of cubical weights. Visual examinations of this material sub-assemblage at Harappa indicate that there are three main macroscopically distinct types of chert represented in it (to see a selection of these refer back to Figure 4.3 B). A *purplish-hued chert/chalcedony* and a *black-brown*-colored chert are the two most abundant types in levels dating to the site's earliest two occupational phases (Ravi and Kot Diji phases). Black-brown cherts occur throughout Balochistan (Aubry *et al.* 1988) and, prior to this study, material of this type found at Harappa was believed to have originated from that region (Meadow and Kenoyer 2001: 24). Artifacts made of a tan to gray-colored (*tan-gray*) chert that often has a distinctive banded pattern have been recovered from strata representing all periods at Harappa. This type appears to have been the only one used during the site's urban phase (Period 3). Tan-gray chert that is sometimes banded is also found at Indus Civilization settlements across the entire Greater Indus region (Ratnagar 2001b: 64) and is widely believed to have originated in the extensive Rohri Hills chert quarries of northern Sindh (Allchin and Allchin 1997: 172).

In this chapter, I present an account of my attempts to determine from which regional geologic sources each of the three main macroscopically distinct types of chert in Harappa's rock and mineral assemblage were most likely derived. For the purplish hued chert/chalcedony, this entailed only the evaluation of that type in relation to chert artifacts in other contemporaneous archaeological assemblages, information in the geologic literature and observations in the field. For the black-brown and tan-gray cherts, however, I was able to directly compare a small set of artifacts (Figure 6.1) from Harappa and the Harappan Period site of Nagwada in Gujarat to samples from potential sources using instrumental neutron activation analysis (INAA). I have provisionally concluded that the purplish hued chert/chalcedony probably comes from volcanic trap rock formations in regions to the north of Harappa. Black-brown chert artifacts from Harappa were almost certainly derived from sources of the site in the Salt Range. Although most of the tan-gray chert artifacts from Harappa and other Harappan sites like Nagwada are probably indeed from the Rohri Hills of Sindh, there are indications that other sources also may have sometimes been used.

Figure 6.4 shows the locations of the four trenches at Harappa from which 24 of the 25 chert fragments analyzed for this study came from. INAA-derived elemental data for these artifacts samples and the geologic to which they were compared are listed in appendices 6.1 through 6.6. Appendix 6.7 lists




**Figure 6.1** Chert samples from Harappa (numbered) and Nagwada (NGW) analyzed for this study. Numbers = appendices 6.1 and 6.4 and below.

the standardized (canonical) discriminant function coefficients for each of the figures (6.18, 6.30 and 6.31) in this chapter that were generated using canonical discriminant analysis (CDA). All regions, sites and chert sources discussed below are noted on figures 6.2, 6.10 and 6.21. I begin with a few brief observations/ remarks on the ubiquity of chert in the Greater Indus region and at Harappa.

## CHERT IN THE GREATER INDUS REGION

Geologically speaking, chert is a rather ubiquitous material. It may form anywhere that "silica, in solution at low temperatures, can precipitate" (Luedtke 1992: 17). This includes sedimentary, metamorphic and volcanic rock formations (Blatt 1992). I have encountered chert in one form or another within most of the regions that I have visited across northwestern South Asia. The ophiolite sequences of the Las Bela, Zhob and Waziristan regions literally contain small mountains composed entirely of massive mixed beds of radiolarian[1)] chert and jasper (Figure 6.3). As their primary context host rocks erode, nodules and fragments of chert and other microcrystalline

1) *Radiolarian* cherts and jaspers contain the mineralized skeletons of microscopic protozoa. Such microcrystalline silicates are sometimes referred to as *radiolarite*.




**Figure 6.2** Regions, sites and chert sources discussed in this chapter.

silicates may be transported and redeposited far from where they originally formed. I have collected bags of secondary context chert and jasper at places ranging from the Makran coast of Balochistan to the Baquka area of western Rajasthan. Still, although chert is widespread in the Greater Indus region, sources where good quality material (e.g. homogeneous unfractured stone for making long blades and other tools) may be acquired are relatively few in number.

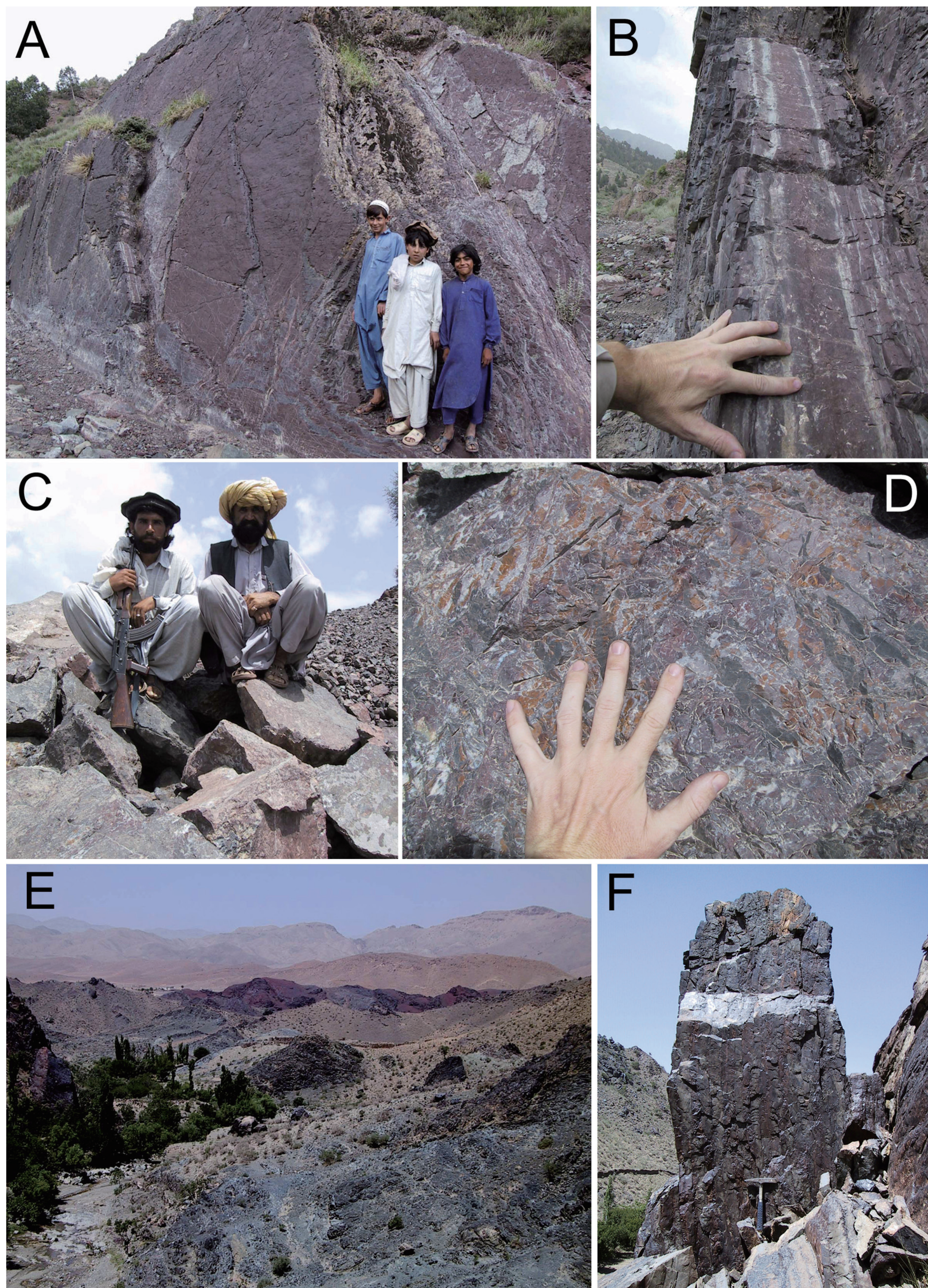



**Figure 6.3** **[A & B]** Bedded, multi-colored ophiolitic chert/jasper formation at Barzai, North Waziristan. **[C]** Men from the Sadgai area, North Waziristan sitting atop blocks of brecciated jasper-chalcedony. **[D]** Detail of Sadgai jasper-chalcedony. **[E & F]** Bedded, multi-colored ophiolitic chert/jasper formation at Ashgar Tangi, northern Zhob District, Balochistan.

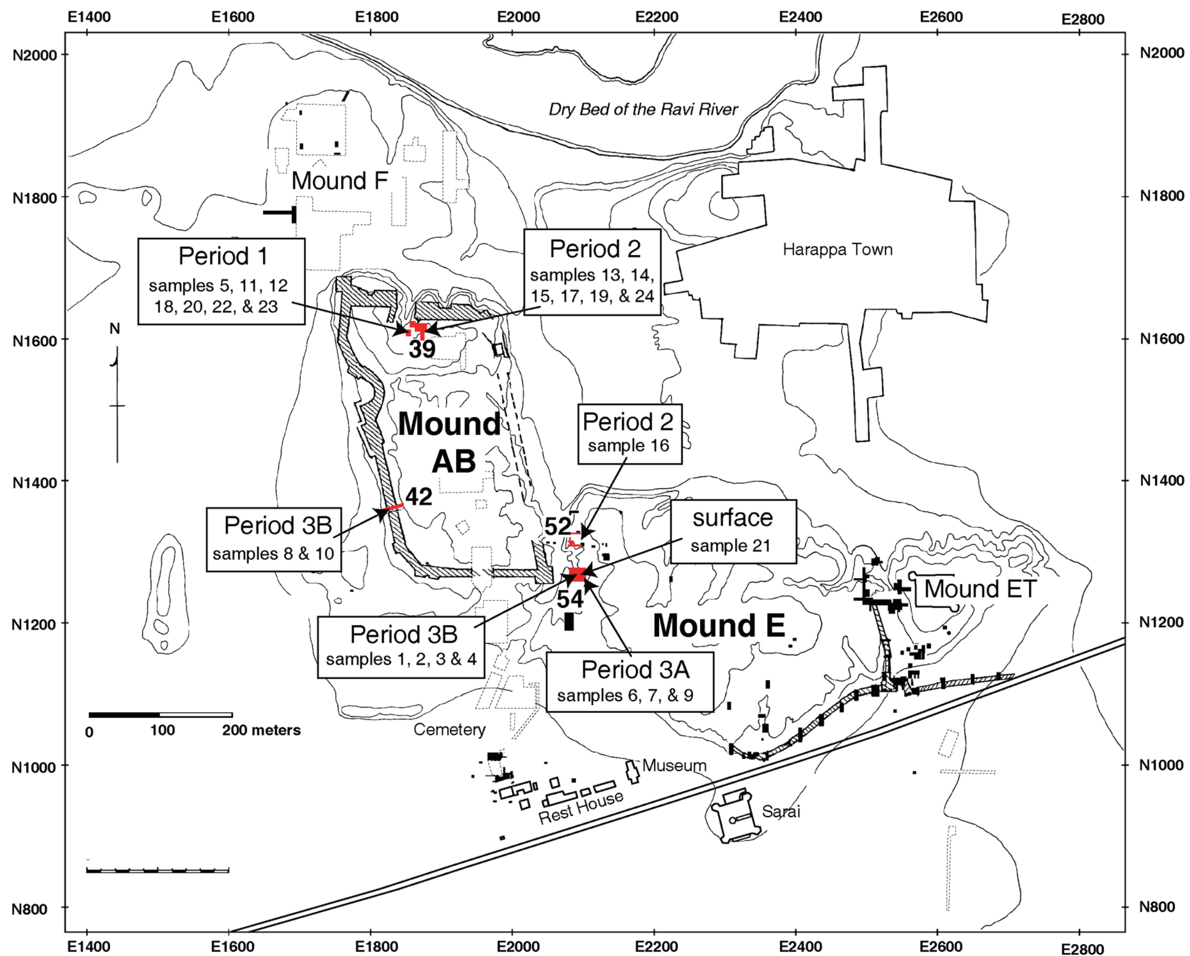



**Figure 6.4** Harappa chert sample locations and contexts.

| **Figure 6.5** Temporal distribution of the 9,325 chert artifacts at Harappa from secure contexts. | |
|---|---|
| **Period 1** | n = 625 *or* 6.70% |
| **Period 2** | n = 105 *or* 1.13% |
| **Period 3A** | n = 161 *or* 1.73% |
| **Period 3B** | n = 932 *or* 9.99% |
| **Period 3C** | n = 7472 *or* 80.13% |
| **Period 4/5** | n = 30 *or* 0.32% |

## CHERT AT HARAPPA

Chert is also ubiquitous at Harappa. It is found in every part of the site and in every one of its chronological phases. Of the 20,967 chert artifacts tabulated by the HARP, 9,325 (44.5%) are from chronologically secure contexts. Figure 6.5 is a table showing how those are temporally distributed. All chert artifacts tabulated at Harappa were individually inspected by HARP team members and their technological attributes were painstakingly recorded. However, information on color, translucency and

macroscopic patterning were not recorded in either the tabulation database or in the Harappa database. Time did not permit me to go back and record such attributes for every one of the chert artifacts from secure contexts but I was able to closely inspect most of the approximately 900 examples that date to periods 1 through 3A and Period 4/5. Only a cursory examination could be given to the remaining 8,400 or so chert artifacts from period 3B and 3C levels. Consequently, the relative abundances of the three main macroscopic types have not yet been calculated. The statements made in this chapter regarding their distributions are based solely upon my impressions from those examinations and my conversations with Prof. Mark Kenoyer, who has dealt with these artifacts for 24 years at the site and knows where and when the different types are and are not found. Although much more work on this major material variety clearly needs to take place, I am confident that my inferences are reasonably accurate and will be borne out when quantitative data eventually become available.

## PURPLE CHERT/CHALCEDONY AND OTHER MINOR EARLY HARAPPAN MATERIAL SUB-VARIETIES

A wide range of microcrystalline silicates were used to make tools during the Early Harappan Period at Harappa (Figure 6.6 A, B & C). In Ravi Phase levels, all three main macroscopic types of chert are present along with a number of other material sub-varieties that include jaspers of different colors and even a few examples of *novaculite* – an opaque white microcrystalline silicate. My general impression is that tool material variety decreased slightly during the Kot Diji Phase. Only the three main chert types seem to be present in those levels. Jasper was still being used then but not to make tools.

Prominent in the lithic assemblages of the Early Harappan Period (especially during the Ravi Phase) is a type of *purple-hued chert/chalcedony*. This type tends to be quite variable in itself. Some examples are a completely opaque (Figure 6.6 B) while others have a semi-translucent (thus the use of the combined term *chert/chalcedony*) light purple appearance with a "smoky" interior banding (the Ravi Phase blade seen on the left hand side in Figure 6.6 C is a good example of the latter). It is very possible that there are actually two or more geologically distinct materials represented by this single macroscopic "type." It is also possible that the purple-hue is due to heat-treatment of the materials (Kenoyer 2001 *personal communication*). If that was the case then the original, unheated stone might have looked like the Ravi Phase blade fragment on the right hand side of Figure 6.6 C, which has same semi-translucent smoky appearance but is tan instead of purple.

I have not yet undertaken any geochemical comparative studies of the purple-hued chert/chalcedonies, the various jaspers or the less abundant types of microcrystalline silicates from Harappa's Ravi and/or Kot Diji phase levels. I have, however, examined lithic assemblages from numerous prehistoric sites around and adjacent to the upper Indus Basin region in an effort to get a sense of what types of microcrystalline silicates were being used by peoples living in the vicinity of the highland areas where the potential sources of those materials were located. Searches of the geologic literature and a number of pertinent observations in the field have also been made. Below, I present some provisional thoughts regarding the potential sources of these Early Harappan raw materials.

The lithic assemblages that I have examined from Early Harappan period sites in the Gomal Plain (Rehman Dheri, Jhandi Babar) and Bannu Basin (Lewan, Tarakai Qila) regions of the NWFP, as well as in the northern Zhob Valley of Balochistan (Periano Ghundai), are replete with radiolarian chert/jasper artifacts (see Figure 6.7 A, B & C for examples). That

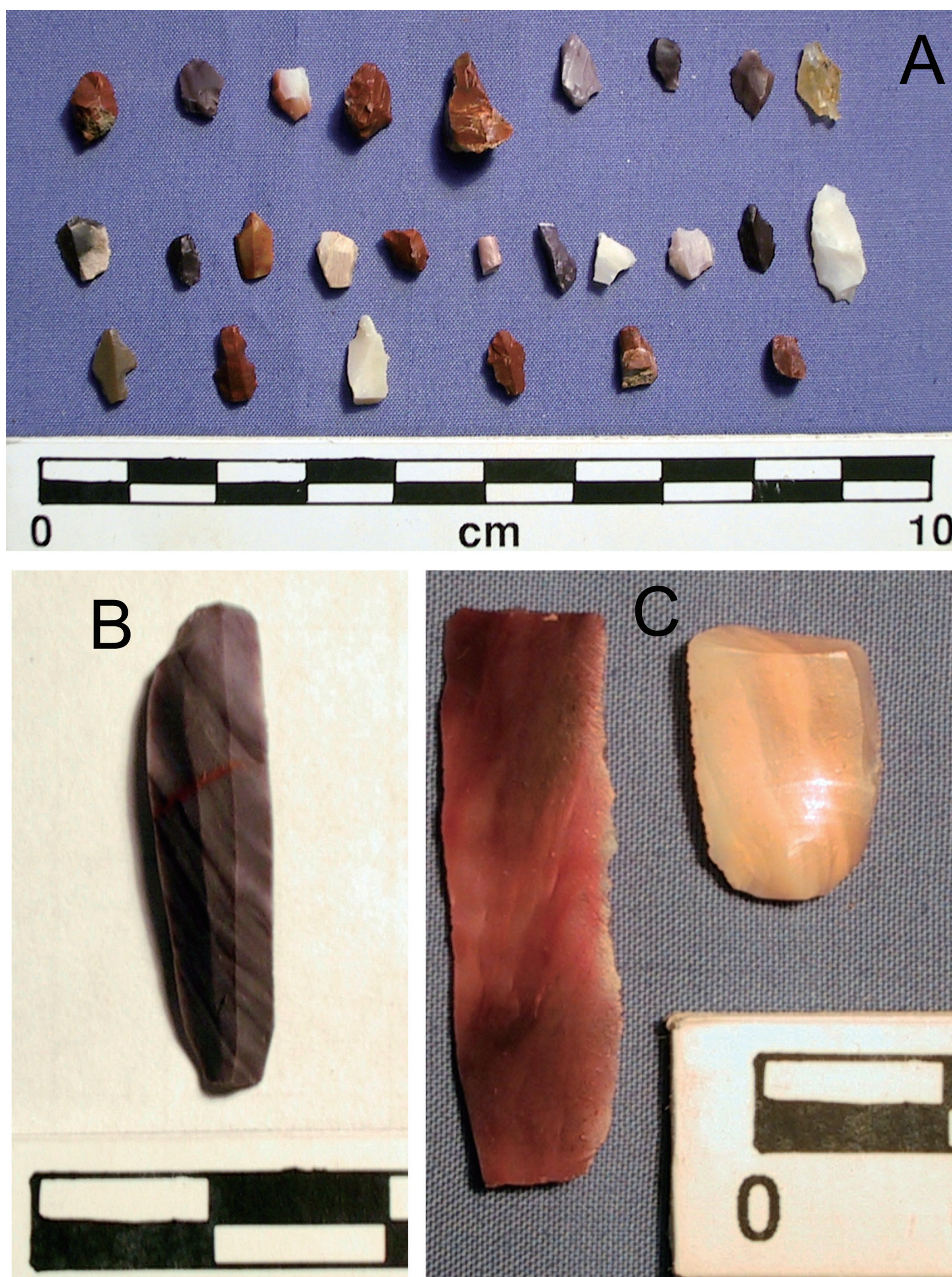



**Figure 6.6** The highly varied Early Harappan Period cherts, chert/chalcedonies and other microcrystalline silicates.

material is found just west of those regions in the ophiolites of Waziristan and the northern part of the Zhob District, Balochistan (recall Figure 6.3). Notice the close similarity between the block of brecciated jasper-chalcedony in the top right hand corner of the Lewan lithics image (Figure 6.7 B) and the Sadgai brecciated jasper-chalcedony (Figure 6.3 C & D). *Some* of the chert/jasper tools from Ravi Phase levels

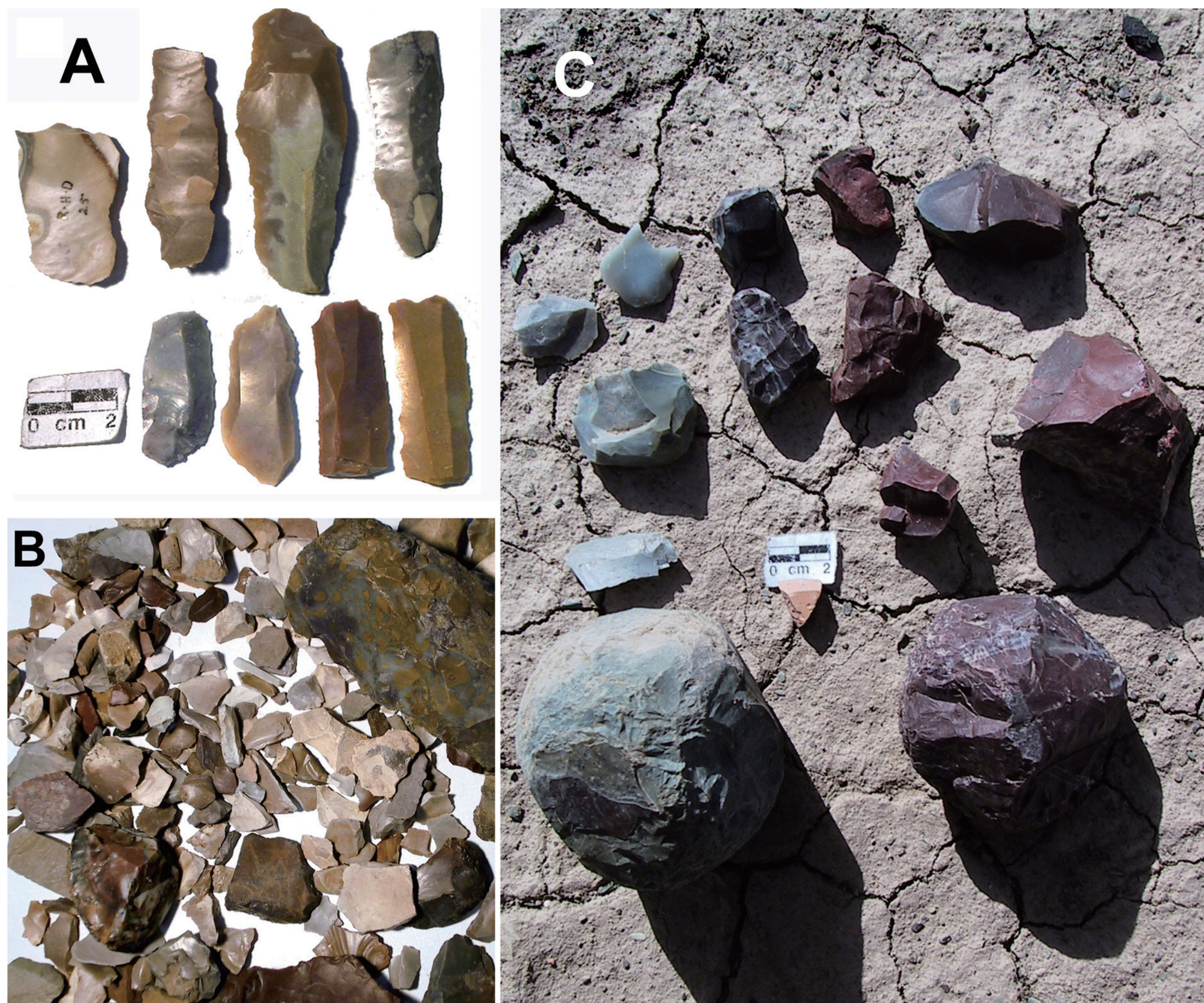



**Figure 6.7** Radiolarian chert-jasper blades and fragments from the sites of **[A]** Rehman Dheri and **[B]** Lewan. Collections of the Sir Sahibzada Abdul Qayyum Museum of Archaeology and Ethnology, University of Peshawar. **[C]** Radiolarian chert-jasper hammerstones and flakes on the surface of Periano Ghundai.

at Harappa appear as if they could be from radiolarian sources such as these.

Jaspers and/or colorful types of chert can also be found in the Salt Range (Figure 6.8) and northern Rajasthan regions, although I have observed that those usually are of very poor quality (i.e., highly fractured and/or brittle). Still, such material can sometimes be used to make tools, as is evident by the worked chert and jasper debris (Figure 6.9) covering the dunes at Gidali (N27° 47’ 25”, E 76° 03’ 37”) in the Sikar District, northern Rajasthan. The people who left behind those remains were either content or compelled to make do with the locally available (Kishore Raghubans *personal communication* 2003) low quality stone. Despite being far removed from any chert sources the early residents of Harappa clearly had more and better options.

I have yet to encounter any stone that even remotely resembles the purple-hued chert/chalcedony from Harappa while doing geologic field studies in Pakistan and India. However, I have seen this exact same material in collections from two other Early Harappan Period sites in the upper Indus Basin region and I suspect it is present at many more. On display in the Kalibangan Museum and pictured in a full color plate in the recently the published report (Bala 2003: 223-228; Plate XXXVI) for that site in western Rajasthan are 25 purple-hued chert/chalcedony microliths that look almost as if they could have been excavated from Ravi Phase levels at Harappa. I have




**Figure 6.8** The colorful but the fractured and brittle chert of the Amb Formation, Nilawahan Gorge, central Salt Range.



**Figure 6.9** Left: The microlith-covered dunes near Gidali, Sikar District, Rajasthan. Right: Examples of the chert and jasper artifacts found there.

also examined tools of identical form and appearance among the artifacts that Aasim Dogar recovered at in the Hakra Culture site of Tala Wala Ther in Cholistan (Dogar 2001). Some of the colorful lithics that Mughal described (1997: 68, Plate 43) as being associated with other Hakra sites in that region are likely more of the same. A "microlith of chalcedony" reported in Period 1 (Early Harappan) levels at Banawali (Bisht 1987: 136) is possibly this material as well. I strongly suspect that this distinctive type of chert/chalcedony will eventually be identified at many more sites of this period across the upper Indus Basin region.

No purple-hued chert/chalcedony artifacts were among the lithic assemblages I examined from sites in the NWFP and, therefore, I doubt this type of

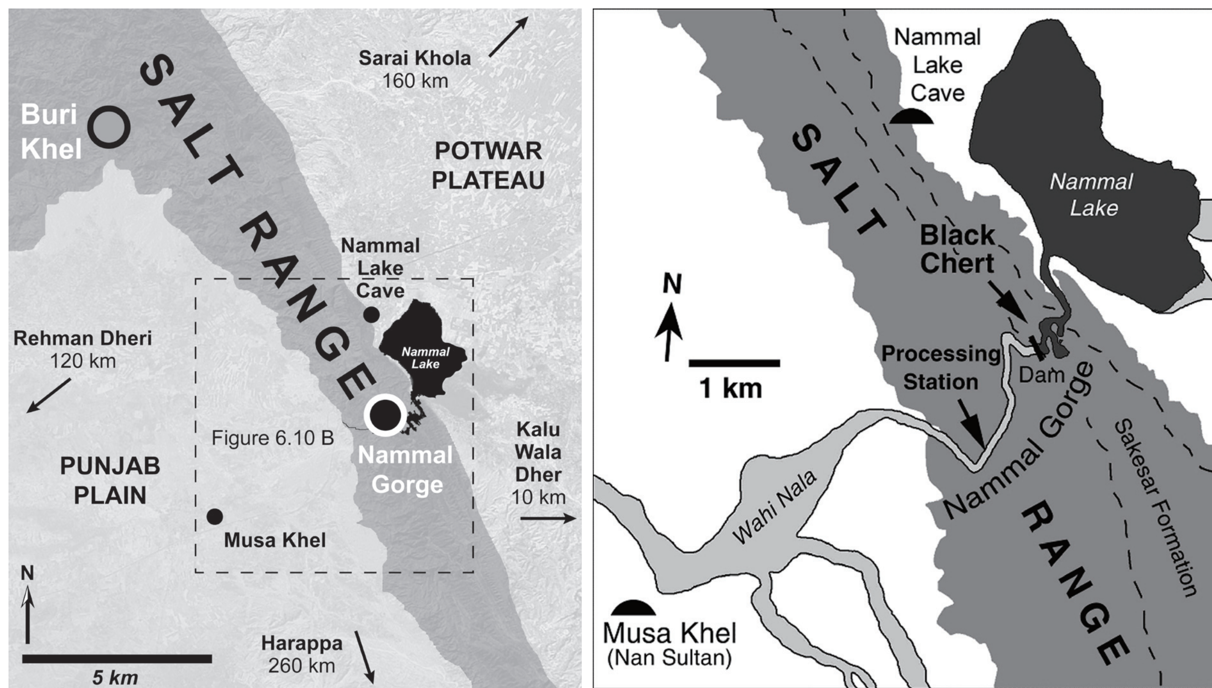



**Figure 6.10** Central Salt Range. **[A]** Chert sources and prehistoric sites. **[B]** Nammal Gorge area.

material was derived from a source in that direction. In addition, although its translucency and visible internal patterning provides the material with a very agate-like appearance, it is quite unlike the agates that I have seen in Gujarat or from elsewhere in the Deccan Traps. There are, however, other agate/chalcedony-bearing volcanic "trap" formations in South Asia. Significantly, two of those are located directly north of the upper Indus Basin: the Khewra Trap in the eastern Salt Range (Jan and Faruqi 1995) and the Pir Panjal Trap of Kashmir (Wakhaloo 1979). Chalcedony geodes have been reported in both of those formations (Wadia 1928: 240; Wynne 1878; 75) and this is one reason why I believe them to be the most promising candidates for the source(s) of the Early Harappan purple-hued chert/chalcedonies. The other reason is that the earliest residents of Harappa clearly had connections to both regions where those formations are located. There are Kot Diji Phase sites throughout the Salt Range (Dar 2002) and excellent evidence (Saar 1992: 13-14) for Kot Dijian or "Late" Kot Dijian interaction with Northern Neolithic peoples living just to the east of the Pir Panjal Range in the Kashmir Valley. The black-brown chert brought to Harappa during the Early Harappan Period almost certainly comes from the Salt Range (I demonstrate this in the next section) and apparently so did some of the alabaster used at that time (demonstrated in Chapter 10). Also the earliest (Ravi Phase) lead artifact found Harappa is isotopically analogous to lead from sources in Jammu and Kashmir (see Chapter 12). Finally, it is worth mentioning that the only reported occurrences in South Asia of novaculite – the white microcrystalline silicate that is occasionally found in Early Harappan levels at Harappa and which I also saw examples of in the Tala Wala Ther collection, are located in Pir Panjal Traps of Kashmir (Dhall *et al.* 1977).

## BLACK-BROWN CHERT

The overwhelming majority of chert artifacts at Harappa are tan to gray colored in appearance. When tools or debris fragments composed of a macroscopically different type of chert are encountered, such as those discussed in the preceding section, they stand out dramatically. Occasionally



**Figure 6.11** Nammal Gorge, central Salt Range.

these different types are found on the site's surface or in strata that have been disturbed. Usually, however, they are met with in trenches where excavations have reached levels *below* the site's Period 3 or Harappa Phase occupation. Most prominent among the distinctive Early Harappan period cherts is the type that will be referred to here as *black-brown* chert. Like the other two "main" types, black-brown chert is actually quite variable in appearance. Nine examples are pictured in Figure 6.1, numbers 16 through 24. The color of this chert type ranges from black (#24) to a medium-brown color (#17). Many examples exhibit the remains of a very light grayish cortex.

HARP excavators immediately recognized that black-brown chert was closely associated with the Early Harappan Period occupation at Harappa (Dales and Kenoyer 1990a: 248). Prof. Kenoyer has recently pointed out, however, that there *could* be sporadic occurrences of this material in the site's later occupational phases. Although I did not come across any examples the black-brown type among the 161 chert artifacts from Period 3A or the 30 from periods 4/5, as I have previously stated, time did not permit me to individually examine each of the 8,400 or so examples from periods 3B and 3C. For those, I made only a quick assessment by looking through the transparent plastic sample bags in which they are stored (grouped by excavation lot and artifact type). If any items among the tan-gray chert flakes, chunks and blades within in the bags had stood out, I would have removed it and inspected it closer. Nothing did, but clearly these assemblages deserve a much more detailed examination of than the cursory look I gave them. Still, if there are any tools or fragments composed of the black-brown type belonging to periods 3B and 3C, I suspect they constitute an extremely small percentage of those assemblages.

Nine black-brown chert artifacts (Figure 6.1: 16 through 24) were selected for a geologic provenience study using INAA. Full details (their HARP



**Figure 6.12** Black-brown chert nodules within the Sakesar Limestone Formation, Nammal Gorge.



**Figure 6.13** Black-brown Sakesar chert tool-preform found in Nammal Gorge.



**Figure 6.14** Black-brown Sakesar chert cores and nodule fragments (red arrows) and a gray Sakesar chert blade (blue arrow) among the Kot Dijian and Harappan Period materials on the surface of Musa Khel.

numbers, contexts and trench information) for each one can be found in Appendix 6.1. Of the nine artifacts, four each are from periods 1 and 2 levels while one is from a disturbed context. The eight samples from secure contexts probably represent around a 5% to 10% sample of the total number of black-brown chert artifacts from their respective chronological sub-assemblages. The nine artifacts were compared to samples collected from three potential sources of black-brown chert located in northwestern South Asia.

### Potential sources of black-brown chert

Prior to this study, the black-brown chert used to make tools during the Early Harappan Period at Harappa was thought to have probably come from sources to the west of the Indus Valley in Balochistan (Meadow and Kenoyer 2001: 24). This is not an unreasonable assumption as chert of this description is known to occur widely across that region (Aubry *et al*. 1988). Still, the assumption had never been tested and so, beginning in mid-2000, I started to seek out potential sources of that material and collect samples for comparative studies. There are, in fact, many geologic formations surrounding the Indus Valley Basin where dark colored cherts occur that, to varying degrees, resemble the black-brown type from Harappa. However, as I previously pointed out, sources of homogeneous unfractured material suitable for making long blades and other tools of the quality used by Harappans are few and far between. In the end, I located three sources or source formations where excellent to just mediocre quality black-brown chert existed.

#### *Sakesar Limestone, Salt Range, Punjab*

In November of 2000, I with undertook an extended period field research with Dr. Syed Baqri

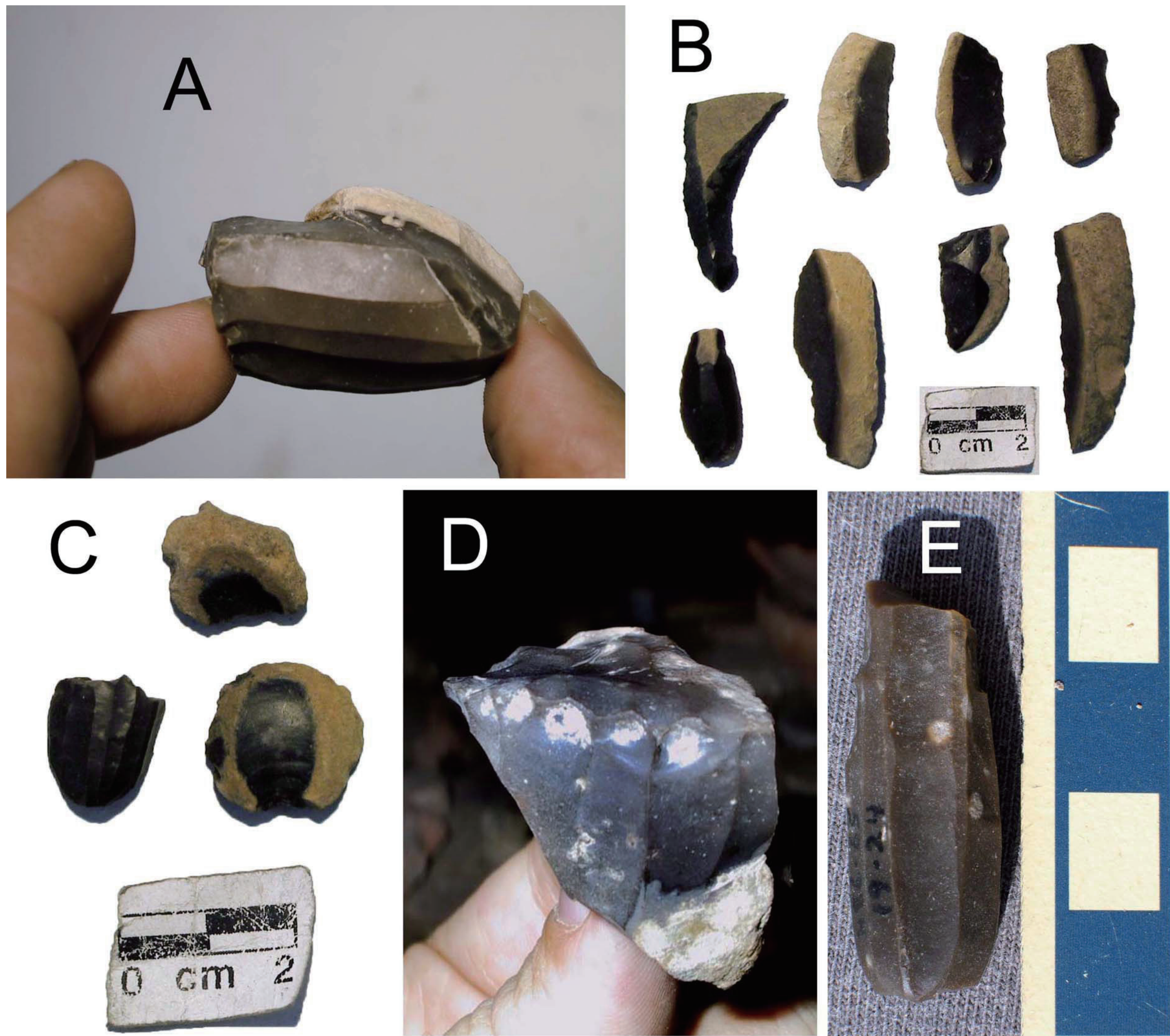



**Figure 6.15** Black-brown Sakesar chert cores and flakes from **[A & B]** Rehman Dehri, **[C]** Lewan, **[D]** Hathial and **[E]** Harappa.

of the Pakistan Museum of Natural History for the purpose of identifying the potential sources of a wide range of rock and mineral varieties used by Indus Civilization peoples. The initial focus of our efforts was the Salt Range. Chert is abundant in these mountains, which mark the northern extent of the Punjab Plain in Pakistan. The materials that we encountered in eastern portion of the range were highly fractured (recall Figure 6.8 A) and would have been unsuitable for tool making purposes. In the central part of the Salt Range (Figure 6.10 A & B), however, nodules of unfractured chert occur in the *Sakesar* formation. This Eocene age limestone runs the entire length of the range but is thickest towards the west where chert is located in its upper portion (Shah 1977: 80). Based on observations in Nammal Gorge and nearby areas and sites, Dr. Baqri and I suggested that the Sakesar Formation was potentially an important source of chert for the Early Harappan peoples at many sites in the upper Indus Basin region (Law and Baqri 2003).

Nammal Gorge (Figure 6.11) is a short defile that transects the Salt Range near its narrowest point. At the head of the gorge there is a British Era dam and a small lake created by it (Punjab Government 1915: 197-198). In former times, this would have been an unobstructed passageway linking the Punjab Plain with the Potwar Plateau. It is quite conceivable

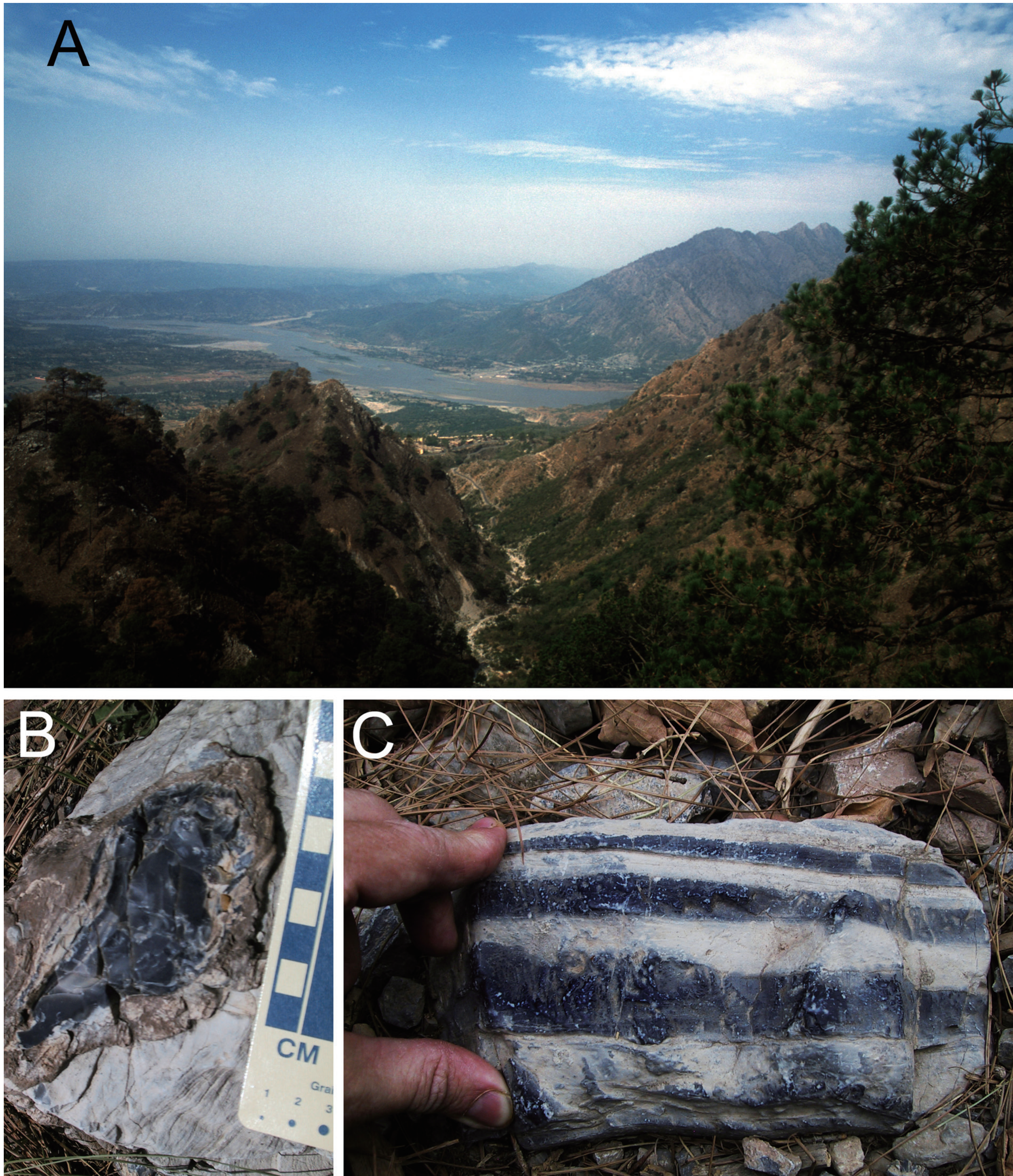



**Figure 6.16** **[A]** The Great Limestone Formation near Riasi, Jammu above the point where the Chenab River emerges onto the Punjab Plain. **[B]** Black Great Limestone chert at Mari nala. **[C]** Black Great Limestone chert at Jangleghari.

that Kot Dijian Phase Early Harappans might have traveled via Nammal Gorge to and from sites in the northern Potwar Plateau region like Sarai Khola (Halim 1972) and Hathial (Khan 1983). Evidence that Kot Dijians dwelled in the immediate vicinity has been found on both sides of the gorge at the sites of Musa Khel (Dani 1971: 32), Nammal Lake Cave (Salim 1992: 44-45) and Kalu Wala Dher (Dar 2002).

Nodules of black-brown chert (Figure 6.12) ranging in size from three to 75 cm occur in the Sakesar limestone near the dam site at the head of Nammal Gorge (N 32° 39' 45", E 71° 48' 1"). They are typically egg-shaped, have a light khaki cortex and can easily be extracted from the host rock at places

where the Sakesar limestone is soft. No old quarries or blade workshops like those found in the Rohri Hills of Sindh (discussed below) were identified but a concentration of flakes and possible tool preforms (Figure 6.13) was observed a few kilometers downstream from the dam. Black-brown Sakesar chert blades, bullet cores, flakes and nodule fragments are found among the Kot Dijian and Harappan Period artifacts (Figure 6.14) on the surface of Musa Khel, which is situated 3 ½ km to the southwest at the gorge's mouth. I have recorded black-brown chert cores and flakes with the light khaki cortex characteristic of Sakesar chert nodules in collections from several Kot Dijian sites outside of the Salt Range region such as Rehman Dheri (Figure 6.15 A & B), Lewan (Figure 6.15 B), Hathial (Figure 6.15 C) and, of course, Harappa (Figure 6.15 D and Figure 6.1 # 17, 18, 20, 22 & 23).

Chert occurs throughout the Sakesar formation (Shah 1980: 26) and so there are probably many potential sources elsewhere in the Salt Range in addition Nammal Gorge. Black-brown as well as light-gray colored types can be found in Buri Khel *nala* (stream), 12 km to the northwest of the gorge. I have also collected samples of black-brown Sakesar chert in the Chichali nala and Saiduwali nala areas, which are located in the extensions of the Salt Range (called the Surghar and Khassor ranges) to the west of the Indus River. Still, chert from Nammal Gorge is the best quality material that I have yet located and is, for several reasons, the strongest candidate for the source of the black-brown chert artifacts from Early Harappan levels at Harappa: it is situated in the immediate vicinity of several Kot Dijian Phase sites; it is located along what would have likely been an important avenue of trade and communication within the Kot Dijian core area; and it is macroscopically *identical* to most black-brown chert artifacts from Harappa right down to its cortex. To best evaluate the degree to which Sakesar chert is or is not chemical analogous to those artifacts, however, samples from other potential sources are required for comparison.

***Great Limestone, Jammu***

Black chert occurs throughout the Neoproterozoic ***Great Limestone*** formation (Figure 6.16 A) of Jammu (Raha 1984). Samples representing this potential source were collected from two locations (Figure 6.16 B & C) around 20 km apart in the Riasi District: Mari nala (N 33° 6' 25", E 74°51' 3") and Jangleghari (N 32° 59' 58", E 75° 2' 32"). Great Limestone chert (at least that from the two locations I sampled) can, at best, be described as a mediocre material for making tools. Although it is not too terribly fractured, it does seem to only occur as thin (≈1 to 2 cm) uneven beds. Striking a long blade using this material would probably prove difficult. However, there are some smaller fragments of black-brown chert from Harappa that could conceivably be this material (such as Figure 6.1 # 16, 19 & 24). Importantly, both sampled locations are situated just 25 km north-northeast of Manda, where an Early Harappan Sothi-Siswal Phase occupation has been identified (Joshi and Bala 1982). Moreover, I later show that at least some of the steatite (Chapter 7) and lead (Chapter 12) artifacts at Harappa probably came from sources in the Great Limestone of Jammu, which are located nearby (≈ 5 km) the chert occurrences sampled for this study.

***Moro Formation, Bolan Pass, Balochistan***

Nodular pods of black-gray chert occur in limestone within the Upper Cretaceous *Moro* Formation of central Balochistan (Aubry *et al.* 1988: 105-106). Samples for this study were collected at a location near Dozan (N 29° 56' 43", E 67° 11' 15") in the Bolan Pass (Figure 6.17 A & B). The quality of Moro chert is mediocre overall. Nodules are firmly affixed in the host rock and are often rife with fractures. Large, fairly homogeneous pieces can occasionally be removed, however. The importance of this source has to do with its position along a

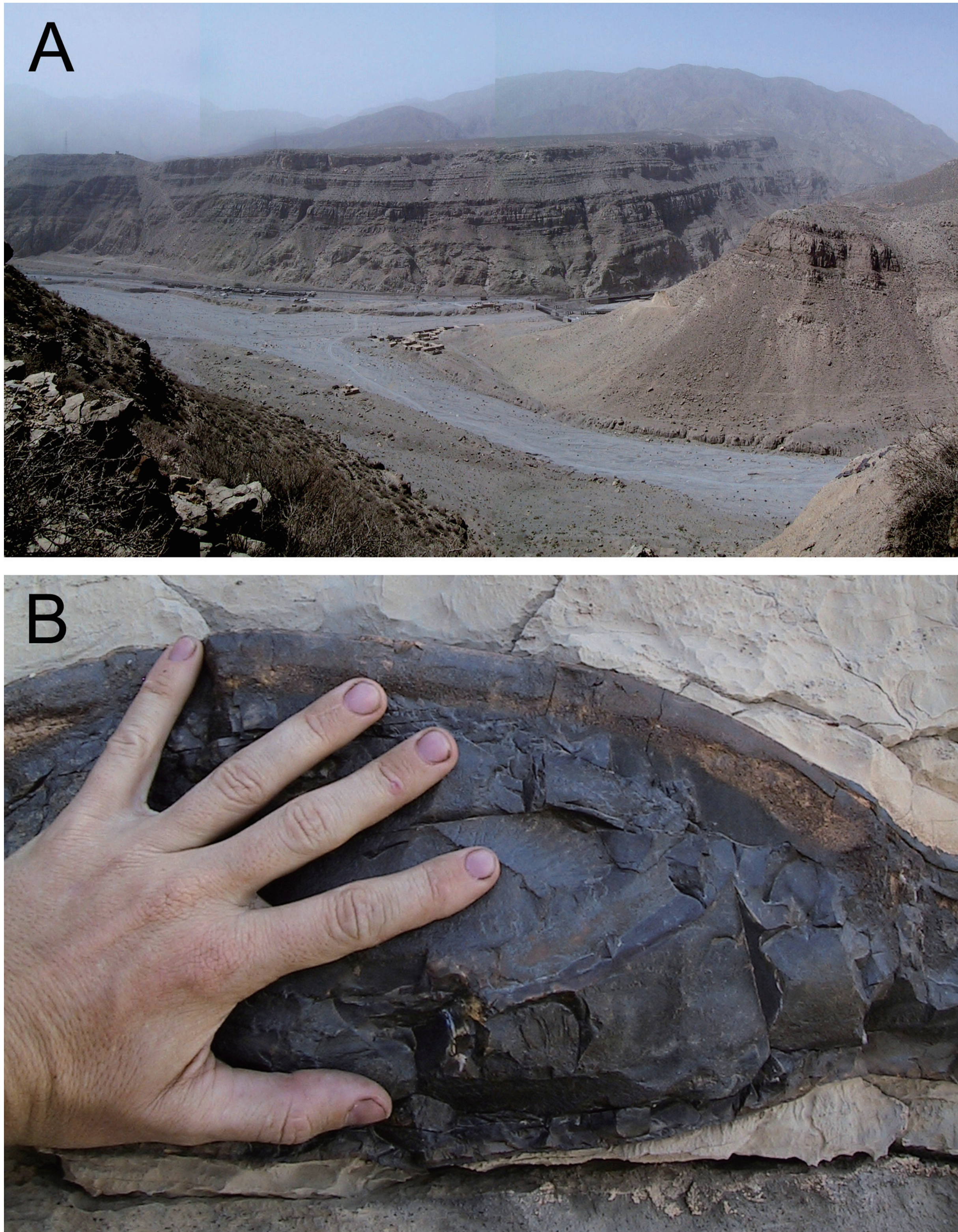



**Figure 6.17** **[A]** The Bolan Pass at Dozan, Balochistan. **[B]** Large pod of black chert in Moro limestone.

major route between the Indus Valley and highland Balochistan as well as its proximity (≈ 75km) to the Early Harappans of Nausharo (I) (Jarrige 1993).

***Potential black-brown chert sources not included in this study***

There are many potential sources of black-brown chert that are not included in this study. Several more are known to exist in Balochistan (Aubry *et al*. 1988).

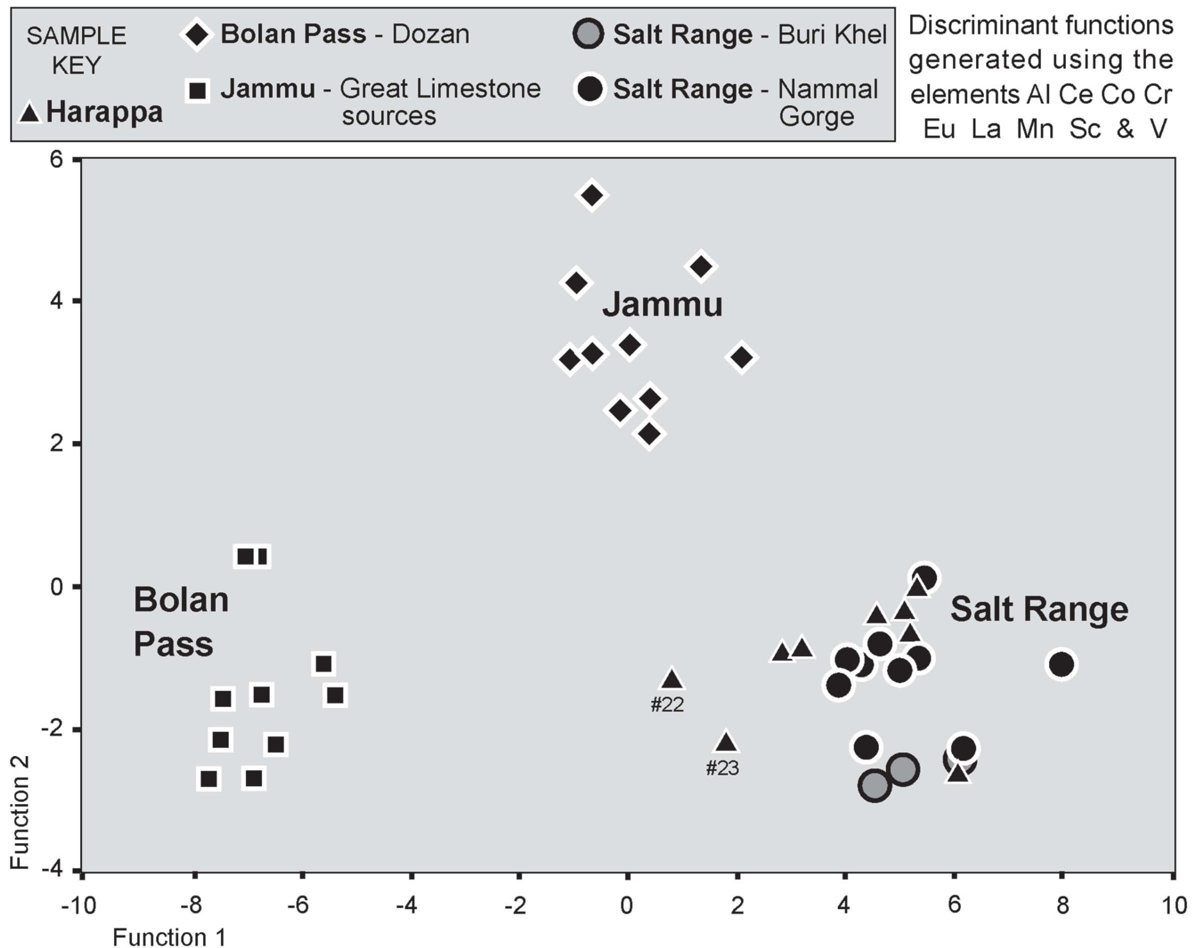



**Figure 6.18** Black-brown chert artifacts from Harappa compared to black chert samples from three geologic sources.

Bedded black cherts similar to those in Jammu occur throughout the Neoproterozoic Krol Formation of the western Himalayas (Gautam and Rai 1997; Shukla *et al*. 2005). Deformed beds of dark Proterozoic chert are found within the various formations of the Mawar supergroup in northwestern Rajasthan (Geological Survey of India 2001b: 21). At the Department of Archaeology and Museums' Excavation Branch in Karachi I have seen black to dark brown cherts in the collections from the sites of Allahdino and Ghazi Shah, which are probably coming from Sindh Kohistan and/or the Kirthar Range. Samples from these and other potential sources will eventually need to be obtained and incorporated into future studies

### INAA/CDA comparison of black chert artifacts to potential sources

Nine black-brown chert artifacts from Early Harappan levels at Harappa (Appendix 6.1) were compared to samples of chert from three potential geologic source areas using INAA-derived elemental data and canonical discriminant analysis (CDA). Details relating to sample preparation, INAA and CDA have already been presented in Chapter 3. The geologic set includes ten samples of Moro chert from the Bolan Pass, Balochistan and ten samples of Great Limestone chert from two locations (five each from the Mari nala and Jangleghari areas) in the Riasi District of Jammu (Appendix 6.2). Thirteen samples of Sakesar chert from the Salt Range (Appendix 6.3) were analyzed: ten from Nammal Gorge and three from Buri Khel. All samples from each regional source formation were treated as a single group for CDA. Archaeological samples were evaluated as ungrouped cases.

In Figure 6.18, all analyzed black-brown chert

samples (archaeological and geologic) are plotted by their first and second discriminant scores, which were generated using the log normalized concentrations of nine elements in those samples – Al, Ce, Co, Cr, Eu, La, Mn, Sc and V. Excellent visual separation between the datapoints representing the three grouped sets of geologic samples is evident. Application of the leave-one-out classification function resulted in a 97% grouped sample cross-validation success rate, which shows that the three groups are also highly distinct statistically. All of the ungrouped archaeological cases plot among or near the datapoints for the Salt Range samples. Based on their Mahalanobis distances to the centroids of the three geologic groups, all artifacts are predicted to belong to the Salt Range group.

In summary, the sets of black-brown chert samples from sources in the Salt Range, Bolan Pass and Jammu regions that were analyzed for this study are, chemically, very distinct from one another. Of those three sources, the nine black-brown chert artifacts from Harappa are, chemically, most analogous to the chert samples from the Sakesar limestone in the Salt Range. In fact, in the majority instances they appear to be quite closely related to them. A few artifacts (#22 & # 23 – refer to Figure 6.1 and Appendix 6.1), although still predicted to belong to the Salt Range group, do plot somewhat away from that source and from the other archaeological samples. I strongly suspect, however, that those are actual examples of Sakesar chert and not materials from some other unrepresented formation that just so happens to be more chemically analogous the Salt Range group than to the other groups. If the two samples in question looked somewhat out of the ordinary (like say #19) then I might be inclined to think otherwise. However, samples #22 and # 23 look *exactly* like Sakesar chert, right down to their cortex. The fact is that the Salt Range source area is represented by only thirteen geologic samples from two locations. Those samples almost assuredly do not represent the full range of chemical variability that Sakesar chert likely exhibits across the extensive formation in which it occurs or, for that matter, at any one location like Nammal Gorge. A larger, more representative sample set will eventually need to be assembled and analyzed. When it is, those outliers will likely be better defined.

In the end, this INAA study suggests that the black-brown chert acquired by Early Harappan period residents of Harappa came from the Sakesar Formation of the Salt Range.




**Figure 6.19** Various tan-gray type chert artifacts from Harappa.
[left-to-right] blade tools, blade core, weight blank or celt roughout?, bead and cubical weight.

## TAN-GRAY (ROHRI?) CHERT

As I stated in the introduction to the preceding section, the vast majority of chert artifacts at Harappa are composed of a material type that has a tan to gray appearance. Many of those objects also possess a highly distinctive banded pattern. Here, these macroscopic variations are collectively defined as the *tan-gray* chert type that is sometimes banded. Approximately one-third of the roughly 20,000 tabulated tan-gray chert artifacts at Harappa are flakes or other debris fragments like those seen in Figure 6.1 – #1 to 6 and 10 to 15. Although most of the remaining two-thirds are tools (blades, drills, awls), a small percentage includes blade cores, objects that may be weight blanks or celt roughouts, an occasional ornament and distinctively Harappan-style cubical stone weights (see Figure 6.19 for examples of these objects). Tan-gray chert is present in every one of Harappa's chronological phases. From Period 3A onwards it *appears* to have been the only type used at the site. In this section, I evaluate the widely held assumption that this type of chert came from sources in the Rohri Hills of Sindh.

The extensive chert deposits of the Rohri Hills – a series of Eocene limestone outcrops in northern Sindh, are assumed by many to have been one of the primary sources, possibly *the* primary source, for the high-quality tan and gray chert artifacts found at Indus Civilization sites from Gujarat to northern Afghanistan (Allchin and Allchin 1997: 118; Francfort 1989: 129; Gupta 1984: 420; Kenoyer 1998: 43, 91; Ratnagar 2001b: 64; Rao 1985: 555; Thapar 1993: 11; Vidale 2000: 36-37). Lending weight to those assumptions are the widespread finds of artifacts composed of the banded sub-type that is only known to occur in the Rohri Hills. Various studies (Allchin 1979b; Inizan and Lechevallier 1997; Kenoyer 1984a; Pelegrin 1994) have documented technological and morphological analogies between tan-gray chert blades from several Harappan sites and those produced at workshops in the Rohri Hills during that period (Biagi and Cremaschi 1991). These observations and studies can now be supplemented with direct artifact-to-source chemical comparisons. In this section, fifteen tan-gray chert artifacts from Harappa and one from the site of Harappan site of Nagwada in Gujarat are compared to geologic samples from potential sources in the Rohri Hills, the NWFP, Balochistan and the Punjab.



**Figure 6.20** The Rohri Hills.

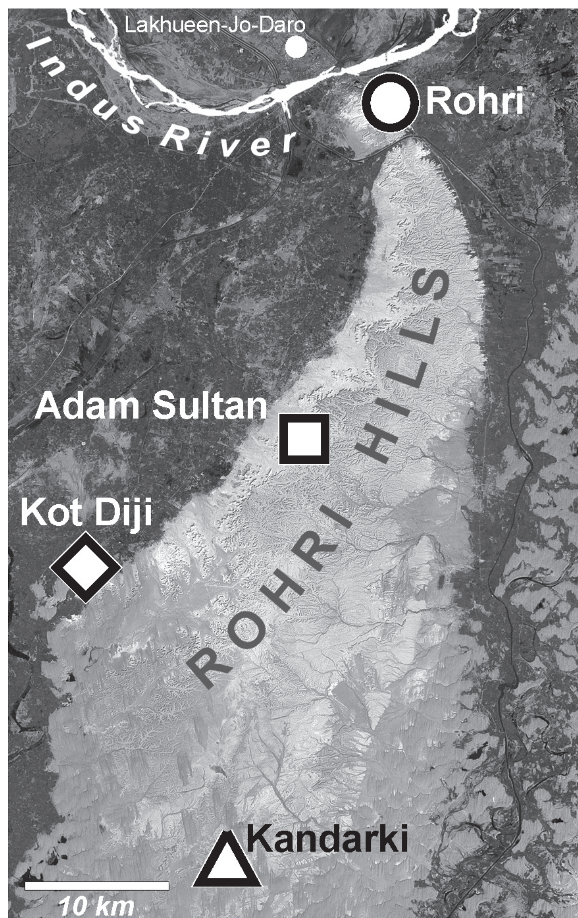



**Figure 6.21** Map of the Rohri Hills showing the four locations sampled for this study.

## Rohri Hills, Sindh

The significance of chert deposits in the Rohri Hills of Sindh (Figure 6.20) began to become apparent when, in the later half of the 19th century, the existence of large concentrations of cores and flakes was first reported there (Evans 1866; Tremlow 1867; Blanford 1875, 1879). Half a century later, de Terra and Paterson noted (1939: 334-35) that many artifacts found in that region were analogous in form to those that had recently been excavated at Indus Civilization site of Mohenjo-daro, 55 km to the west of the hills. Research in the 1970s by Bridget Allchin and others (Allchin 1976; Allchin *et al.* 1978) and, more recently, by members of the joint Pakistani and Italian project in the region (Biagi and Shaikh 1994), has subsequently produced a wealth of evidence that documents the intensive exploitation of chert resources in the Rohri Hills from the Lower Paleolithic through the Harappan Period.

In November of 2000, chert from four localities in the Rohri Hills (Figure 6.21) was sampled during field research in that area with G.M. Veesar of the Department of Archaeology, Shah Abdul Latif University, Khairpur.

### *Rohri*

Nodules of tan-gray chert occur on the extreme northern tip of the Rohri Hills (Figure 6.22) adjacent to the modern town of Rohri and approximately five kilometers southeast of the Harappan Period site of Lakhueen-Jo-daro (Kazi 1989). The material at this location exhibits a pattern of parallel concentric bands (Figure 6.23) and is *identical* in appearance to the chert that seems to have been the preferred stone for making cubical weights used at Harappa (Vats 1940: 361; Figure 6.13 *bottom right*) and many other Indus Civilization settlements. With the exception of a recently reported occurrence near Kandarki along the southern fringes of the Rohri Hills (Nilofer Shaikh *personal communication* 2004), no other sources of tan-gray chert with this distinctive banded pattern are presently known to exists elsewhere in the Greater Indus region. Unfortunately, this source may not exist much longer as the outcrops around Rohri town are rapidly being destroyed by limestone mining operations (Biagi 2006).

### *Adam Sultan*

The chert that occurs in the central portion of the Rohri Hills generally appears to be the most homogeneous (in terms of both color and texture) in the region. Nodules collected at a location near the tomb of Adam Sultan were mostly a uniform medium gray throughout, with the chert grading into a brown-gray within 1 to 2 cm of the cortex. Visually, this material is indistinguishable from that found at the Harappan Period quarries and workshops (Figure 6.24) documented slightly farther (≈ 5 km) to the north near the shrine of Shadee Shaheed (Shaikh and



**Figure 6.22** Limestone mining at Rohri, on the northern tip of the Rohri Hills.



**Figure 6.23** Banded tan-gray chert from Rohri.

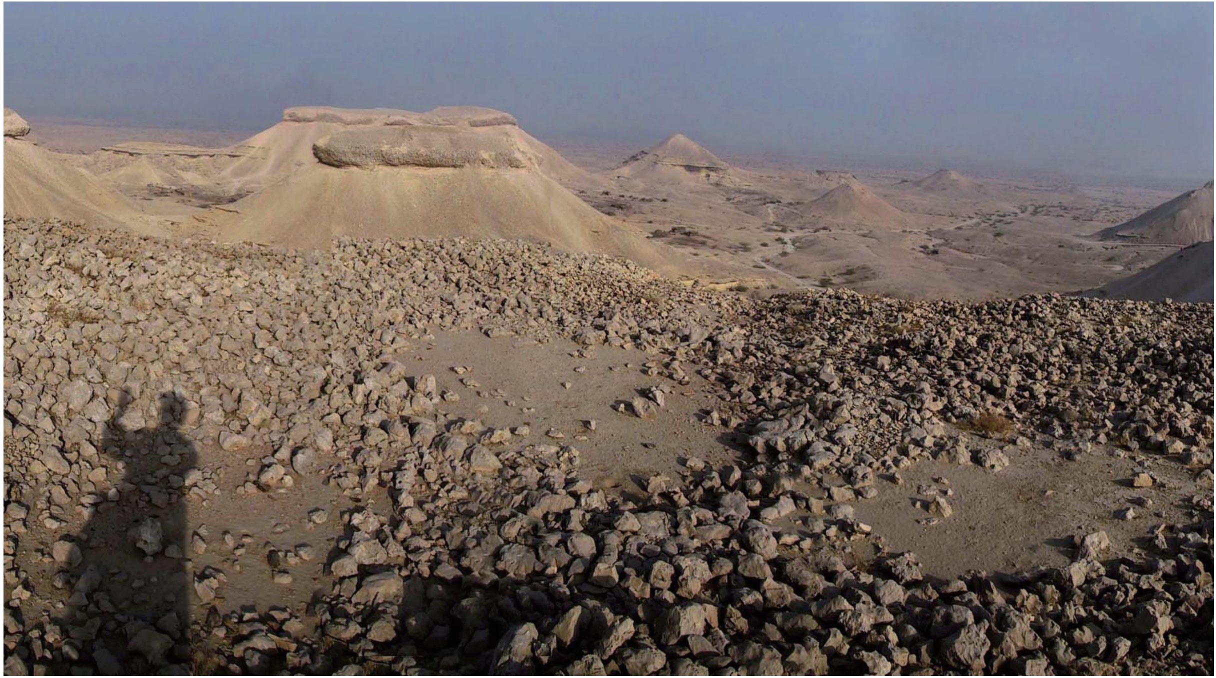


**Figure 6.24** Harappan Period quarries and workshops near Adam Sultan at Shadee Shaheed.



**Figure 6.25** Chert debris covering the ground surface at Shadee Shaheed.

Biagi 1999). The ground surface at that location is completely covered with debris (Figure 6.25) from the production of highly standardized chert blades.

***Kot Diji***

The famous Early Harappan and Harappan Period site of Kot Diji (Figure 6.26 A) is situated on the southwestern margin of the Rohri Hills (Khan

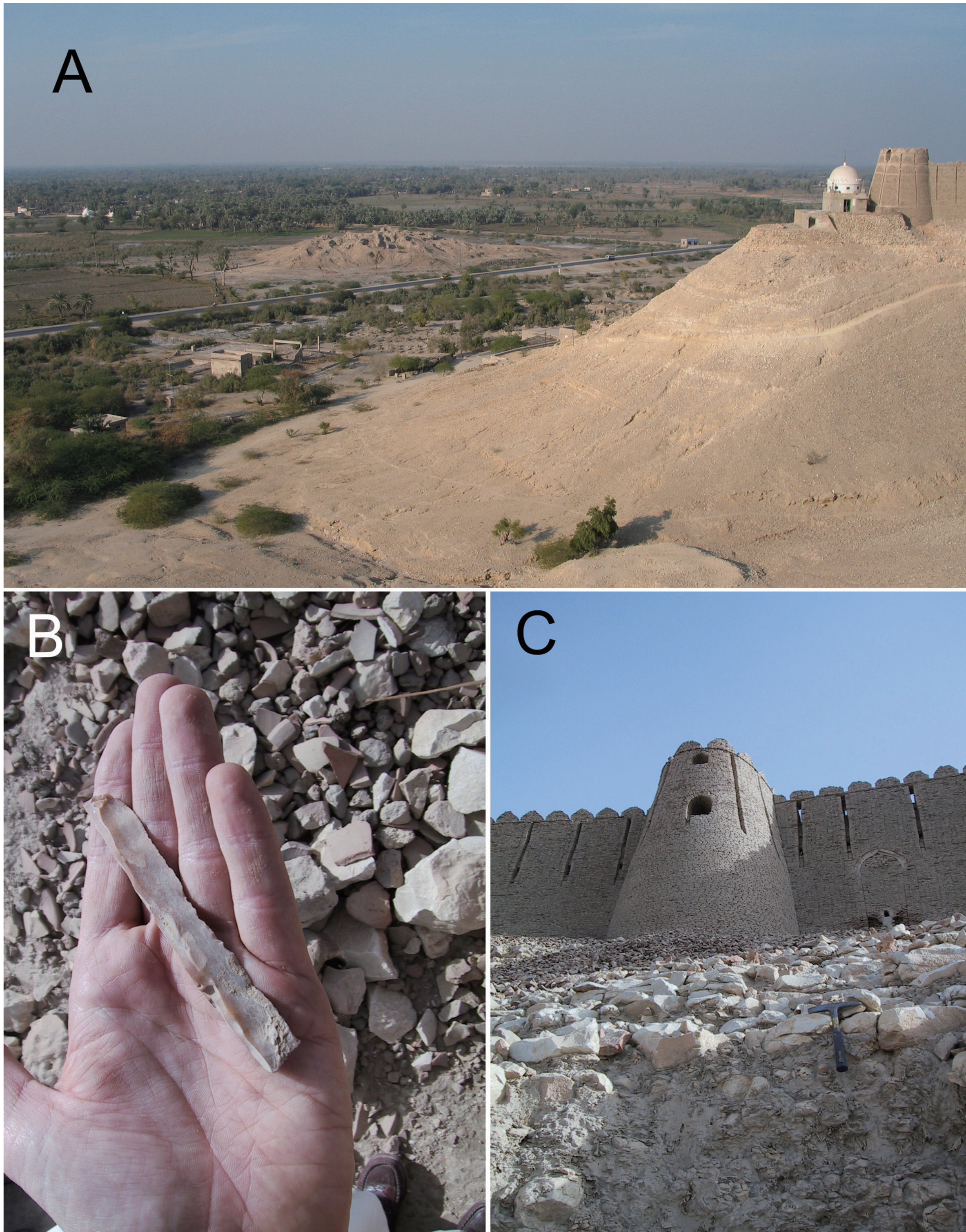



**Figure 6.26** **[A]** The prehistoric site of Kot Diji adjacent to the fort of the same name. **[B]** A tan chert blade at Kot Diji. **[C]** Chert nodules eroding from the limestone bedrock below the Kot Diji fortifications.

1965). The chert artifacts on the surface of the site (Figure 6.26 B) and the chert nodules eroding from the hill slope 200 m to the east (Figure 6.26 C) tend to have a brown and gray mottled appearance.

*Kandarki*

The southern extremities of the Rohri Hills consist of intermittent low-lying limestone mesas surrounded by sand dunes called the Kandarki Hills



**Figure 6.27** The low-lying limestone mesas called the Kandarki Hills.



**Figure 6.28** Chert blade production debris at Kandarki.




**Figure 6.29** **[A]** Tan chert sample from the Mohmand Agency, NWFP. **[B]** Gray Chilton Limestone chert samples from the Kalat District, Balochistan. **[C]** Gray Sakesar chert samples from Buri Khel nala - Salt Range, Punjab.

(Figure 6.27). The light brown and gray cherts found here tend to contain more inclusions and have a coarser texture than materials found farther to the north. The material is, nonetheless, of excellent quality, as is evidenced by the numerous workshops discovered in the area (Figure 6.28).

### Other potential sources of tan-gray chert

Although the rich, high-quality chert deposits of the Rohri Hills were optimally located with regard to supplying material to settlements across the Harappan realm (i.e., situated in the central Indus Basin along the principal north to south running waterway/ trade route), they together constitute only one of many potential source areas around the Greater Indus region from which Harappan consumers could have acquired this resource. For comparative purposes, samples of brown or gray chert were collected from potential sources three additional regions located outside of the northern Sindh area – the NWFP, Balochistan and the Punjab.

#### *Mohmand Agency, NWFP*

Little published information exists regarding chert occurrences in the northern part of the NWFP. However, geologic samples from that region in the collections at the Department of Geology, University of Peshawar bear a strong resemblance to the darker types of tan-colored chert found in the Rohri Hills as do many of the chert artifacts from prehistoric sites in the Swat Valley on display in the Swat Museum at Saidu Sharif (*personal observations*). For this study, dark tan chert (Figure 6.29 A) was obtained from a limestone crushing plant at Dand, in the Mohmand Agency. The limestone and the chert at the plant reportedly came from formations near the border of the Mohmand and Malakand agencies (Irshad Ahmad, Centre of Excellence in Geology, University of Peshawar – *personal communication* 2001). Clearly this was not the best way to obtain samples but I felt that inclusion of material from this region in the dataset was essential.

#### *Kalat, Balochistan*

Cherts that occur in Balochistan are highly variable, which is not surprising given the large area and diverse geology that the province encompasses. Thierry Aubry and others (1988) made a sizeable collection of samples from across that region, which are now stored at the Department of Geology, University of Balochistan-Quetta. Access to these samples was graciously provided by Drs. Khalid Mahmood and Mehrab Khan of the Center of Excellence in Mineralogy, University of Balochistan-Quetta. In the Kalat District, nodules of yellowish-gray to gray-colored chert are found in Chilton limestone (Figure 6.29 B). For this study, five examples of gray Chilton chert were selected from a set of materials collected near the village of Gajan (ibid.: 103).

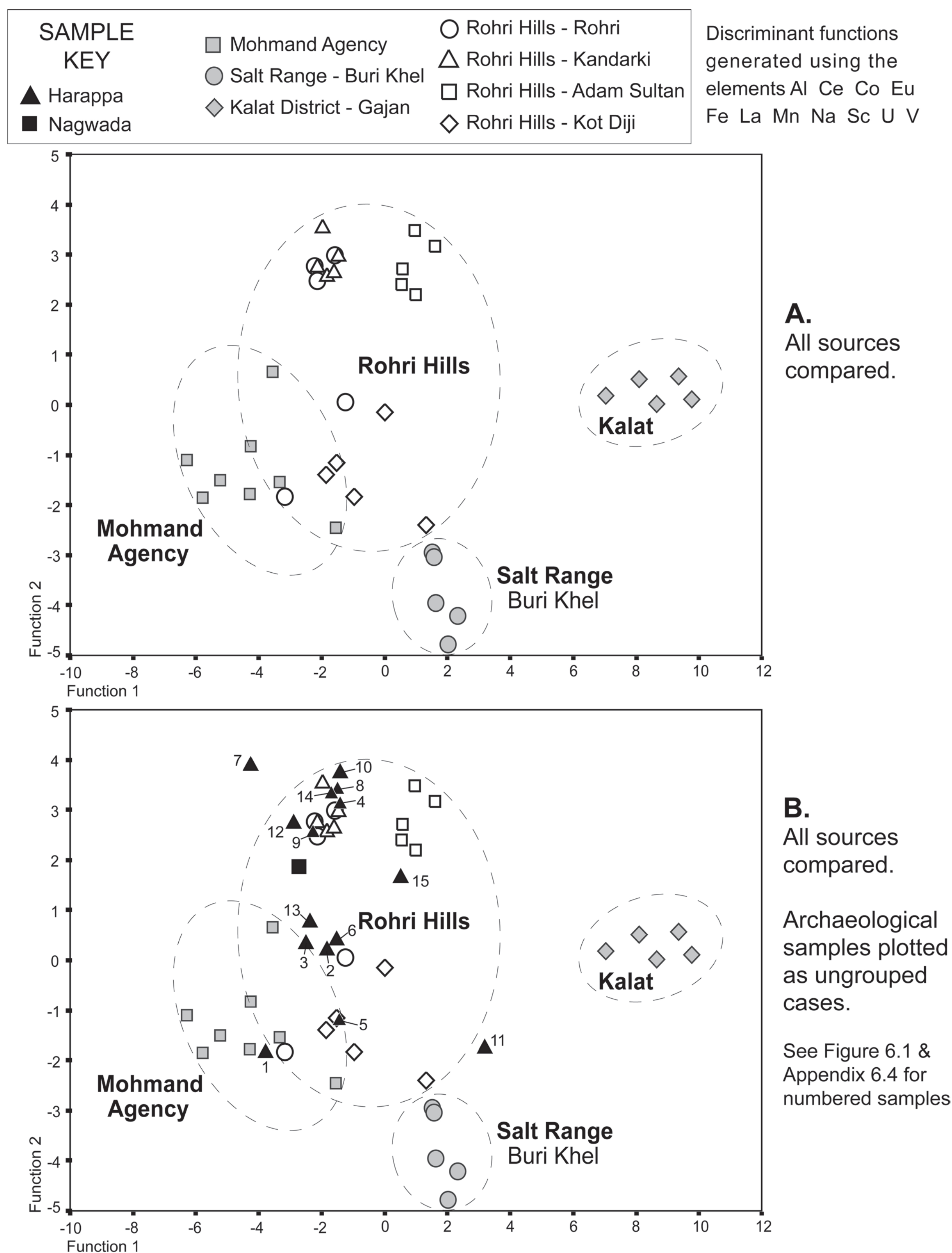



**Figure 6.30** INAA results: Tan-gray chert artifacts from Harappa and Nagwada compared to geologic samples from sources in four regions.

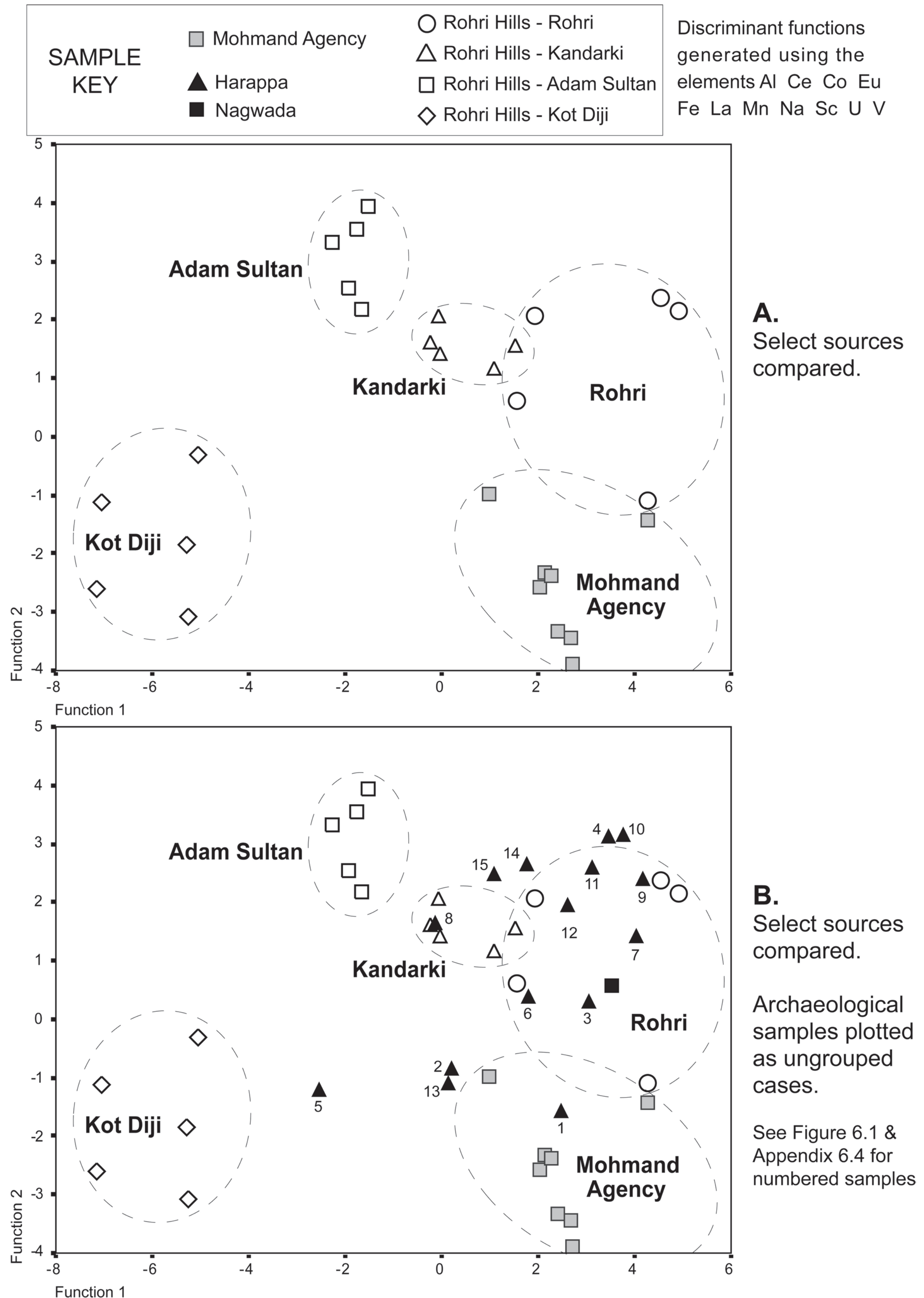



**Figure 6.31** INAA results - Tan-gray chert artifacts from Harappa and Nagwada compared to geologic samples from sources in select regions.

**Figure 6.32** Percentage of chert artifacts at Harappa sampled by context.

| Period | total chert artifacts | number analyzed | percent sample |
|---|---|---|---|
| 1 | 625 | 7 | 1.12% |
| 2 | 105 | 7 | 6.67% |
| 3A | 161 | 3 | 1.86% |
| 3B | 932 | 6 | 0.64% |
| 3C | 7,472 | 0 | 0% |
| 4/5 | 30 | 0 | 0% |
| Surface & disturbed | 11,642 | 1 | 0.009% |
| All from secure contexts | 9,324 | 23 | 0.25% |
| Total | 20,967 | 24 | 0.11% |

*Buri Khel, Salt Range, Punjab*

In the central portion of the Salt Range, Punjab Province, nodules and fragments of a light gray-colored chert (Figure 6.29 C) are found in the bed of Buri Khel nala. Although I did not locate in situ deposits of this material, it most probably derives from the nearby Eocene limestone of the Sakesar Formation as it was found in association with black-brown Sakesar chert fragments. Fifteen kilometers south of this location, I observed blades made of a light gray chert identical in appearance to the Buri Khel material on the surface of the Early Harappan and Harappan period site of Musa Khel (Dani 1971: 32).

*Tan-gray chert sources not included in this study*

It is important to point out that there a number of potential tan-gray chert sources that are not included in this study. Southern Sindh is one area that will need to be intensively sampled in the future. Bridgett Allchin and others (1978) reported chert quarries and working floors on a limestone ridge adjacent to Milestone 101 near the modern city of Hyderabad. In that same area, chert beds continue in the Eocene limestone hills to the west of Kotri town (Blanford 1879: 142). Paolo Biagi's recent (2005) surveys there revealed only Paleolithic workshops, which suggest that the exploitation of material from the region probably ceased well before the Harappan Period. The material reported was light brownish gray in color (Biagi 2005: 1). Another occurrence lay south of Kotri at Tharro Hill, where N.G. Majumdar observed (1934: 20-21) "innumerable" chert flakes and cores and suggested that the location was a "centre of flint-knapping industry." To the northwest of Kotri, not far from the site of Ghazi Shah, Majumdar noted (ibid.: 122) a heavy concentration of worked and unworked chert at Bandhni Nai.

Balochistan is also a region where much more exploration for potential chert sources needs to take place. Dr. Syed Baqri recently observed an extensive chert working area while doing palaeontological fieldwork in the Dera Bugti region of east-central Balochistan. Although his examination was cursory, the archaeological remains and the tan-gray chert found there were considered to be very reminiscent of that at similar activity areas in the Rohri Hills (S.R.H. Baqri *personal communication* 2004).

## INAA/CDA comparison of tan-gray chert artifacts to potential sources

The fifteen tan-gray chert artifacts from Harappa (Figure 6.1 # 1 through #15; Appendix 6.4) selected for INAA/CDA comparison to the geologic sources described above were excavated from secure contexts ranging from Period 1 through Period 3B on Mound AB and Mound E (Figure 6.4). The samples were judiciously chosen to represent the range of variability evident among artifacts defined as being composed of this material type. A few examples (# 1, 6 & 11) were specifically selected because, although they are tan-gray in appearance, they have a somewhat "un-Rohri Hills-like" texture or cortex.

Dr. Kuldeep Bhan of the Department of Archaeology, Maharaja Sayajirao University, Baroda provided the single tan-gray chert blade fragment (Figure 6.1 NGW; Appendix 6.4 bottom row) recovered in Harappa Period levels at the Indus Civilization settlement of Nagwada in northern Gujarat (Figure 6.2). Chert artifacts of this type were found throughout that site's stratigraphic sequence (they are described in Hegde *et al.* 1988 publication as being "ivory" colored). The excavators wrote that "ivory colored chert is not reported from anywhere near Nagwada" and that "it would be interesting to know if they came all the way from the Rohri Hills" (Hegde *et al.* 1988: 62-64).

The geologic dataset includes 20 tan-gray chert samples from the Rohri Hills – five samples each from the four locations visited in that region (Appendix 6.5). Eight samples from sources in the Mohmand Agency, NWFP and five each from Buri Khel, Punjab and the Kalat District, Balochistan round out the dataset (Appendix 6.6). Details relating to sample preparation, INAA and CDA were presented in Chapter 3. Data for eleven elements (Al, Ce, Co, Eu, Fe, La, Mn, Na, Sc, U and V) are reported in the appendices.

All sampled tan-gray chert sources are included in the initial CDA of the geologic and archaeological datasets (Figure 6.30 A). Although the four Rohri Hills locations are treated as separate groups for the analysis, I have placed dashed ellipse around all samples from that region, as well as ellipses for each of the other three groups, in order to demarcate the approximate areas where the regional sources plot. These ellipses are hand drawn visual guides and do *not* represent statistical confidence intervals. Good visual separation, overall, between the different sources is evident. There is a degree of overlap between samples from Rohri Hills deposits and those from the Mohmand Agency source. The Kalat and Buri Khel sources both group separately, however. Exactly 73.7% of leave-one-out cross-validated grouped geologic cases were classified correctly. The misclassifications that resulted in that percentage were among the Rohri Hills sources (not unexpected as they are from the same broad geologic formation) as well as between samples from two of the Rohri Hills locations (Rohri and Kot Diji) and the Mohmand samples.

When the chert artifacts from Harappa (solid black triangles) and Nagwada (solid black square) are considered as ungrouped cases (Figure 6.30 B), the majority including the Nagwada artifact plot among the geologic samples from the Rohri Hills. The CDA-predicted group memberships for all samples is one of the Rohri Hills sources (Rohri = 12 artifacts including the Nagwada sample, Kot Diji = 2, Kandarki and Adam Sultan = 1 each). Several artifacts, however, fall in or near the area where samples from the Rohri Hills and Mohmand sources overlap. Since this is an area where misclassification of some cross-validated geologic samples occurred there is the possibility that some artifacts in this area, although predicted by CDA to belong to a Rohri Hills source, could actually be an outlier of the Mohmand source. Sample number 1 (H2001/2939-27) plots especially close to that group and, in fact, was one of the samples that was chosen because it had a somewhat "un-Rohri Hills-like" appearance to it. Similarly, sample number 11 (H96/7500-30) plots away from the main group of artifacts toward the Salt Range samples from Buri Khel. Upon closer examination, this artifact *could* be grayish-colored Sakesar chert and it does come from a context (Period 1) when material of that kind was being used at Harappa.

For the second CDA (Figure 6.31 A), only the Mohmand Agency cherts and samples from the four locations in the Rohri Hills are compared. The Buri Khel and Salt Range groups were removed from the geologic dataset because none of the artifacts from Harappa were predicted to belong to them and they did not overlap with the other sources. Where as the Kot Diji and Adam Sultan groups are distinct, varying degrees of overlap exists between the Kandarki and




**Figure 6.33** A large tan-gray chert nodule with its cortex removed. From the Harappa Museum Reserve Collection.

Rohri sources as well as between the Rohri and Mohmand Agency groups. This time, only 60.7% of cross-validated grouped cases were correctly classified. The lower cross-validation success rate is partially due to the removal the two most geochemically distinct groups (Buri Khel and Kalat) from the dataset and partially due to the misclassification between Kandarki, Rohri and Mohmand samples.

Most of the chert artifacts still plot among the Rohri Hills sources (Figure 6.31 B). Ten were predicted by CDA to belong to the Rohri group while three others (numbers 5, 8 and 15) were assigned to the Adam Sultan group. The latter prediction might seem unusual as none of the artifacts appear to fall near the Adam Sultan group on the plot. Recall, however, that group membership predictions are based upon proximity to a group centroid in multi-dimensional space, whereas only two dimensions can be represented on the plot. Interestingly, two chert fragments from Harappa (numbers 2 and 13) are now predicted to belong to the Mohmand group. Although those artifacts may indeed have come from that source, it is possible they are Rohri Hills outliers that just happen to fall closer to the Mohmand group centroid. It is worth pointing out again that the overlap between samples from the Rohri and Mohmand groups contributes, in part, to the misclassification of nearly 40% of the geologic cases. Chert artifacts derived from either of those source regions would be subject to the same risk of misclassification. Significantly increasing the number of geologic samples analyzed may eventually

**Figure 6.34** Chert artifacts with cortex and nodules fragments at Harappa.

**A**

Percentage of artifacts with cortex in Harappa's chert assemblage through time.

| *Period* | *total chert artifacts* | *number w/ cortex* | *percent w/ cortex* |
|---|---|---|---|
| **1** | 625 | 24 | 3.84% |
| **2** | 105 | 8 | 7.62% |
| **3A** | 161 | 10 | 6.21% |
| **3B** | 932 | 35 | 3.76% |
| **3C** | 7,472 | 368 | 4.93% |
| **4/5** | 30 | 6 | 20.0% |
| **Surface & disturbed** | 11,642 | 828 | 7.11% |
| **ALL** | 20,967 | 1,279 | 6.10% |

**B**

Banded chert nodule from the Rohri Hills (Rohri)

Banded chert flake with nodule cortex (Period 3C - Mound ET)

**C**

*Above* - Chert nodule from the Rohri Hills (Adam Sultan)

*Below* - Chert nodule fragment from Harappa (Period 3C levels below the Mughal Sarai)

help mitigate this problem by providing a clearer understanding of the geochemical variation in chert deposits both within and between the regions being compared. Nevertheless, it is still possible to state that when artifacts from Harappa are compared to all of the chert deposits examined for this study, they are, on the whole, much more analogous to material from the Rohri Hills (especially the deposit near Rohri town), than they are to any of the other sources. There is limited evidence that the chert used to make a few of the artifacts might have been derived from a source outside of the northern Sindh region, perhaps one in the Mohmand Agency, NWFP. The "ivory" colored chert blade from Nagwada appears to have come from the Rohri Hills.

## CHAPTER CONCLUSION

Geologic provenience studies of chert at Harappa

are still at a very early stage. The sample size (Figure 6.32) represented by the 24 artifacts thus far analyzed from the site is miniscule (0.11%) in relation to the total number of chert artifacts recovered (and this is not taking into account the fact that the amount recovered assuredly represents the barest fraction of what actually exists at the site). Sample size is slightly better (0.25%) when considered as a percentage of chert artifacts just from secure contexts and even quite good for certain chronological sub-assemblages (Period 2 at 6.67% is the best sampled). Hundreds more artifacts will need to be analyzed, however, in order to obtain a sample that is reasonably representative both temporally and spatially (75 analyses are needed for just a one percent sample of the recovered Period 3C sub-assemblage). At this point it is simply not possible to say much about site-wise synchronic variations in chert source usage. Discussions of diachronic source usage are possible with the understanding that supporting INAA data is limited. That being said, the INAA results along with general observations about the composition and distribution of the chert assemblage at Harappa have provided important new insights into Early Harappan and Harappan Period chert acquisition networks. Some past assumptions about where certain types of material were obtained clearly need to be revised while others can now be supported for the first time with direct artifact-to-source comparative data. The major findings and evident trends, in summary, are as follows:

The founders and early residents of Harappa acquired three main types of chert. Based on field observations, a review of the geologic literature and studies of lithic assemblages at other Early Harappan sites, I have concluded that the most probable source or sources of the purplish-hued type of chert/chalcedony used during Periods 1 and 2 are the Khewra and/or Pir Panjal volcanic trap rock formations located approximately 225 km and 400 km to the north of the site respectively. Field reconnaissance in the eastern Salt Range and Kashmir, along with the eventual analysis of chert/chalcedony samples from those regions, will be required to confirm this, however. The black-brown chert used during the same Early Harappan periods was almost certainly derived from sources beginning around 250 km to the northwest of the site in the Sakesar limestone of the central and western Salt Range, rather than from sources in Balochistan as previously thought. Artifacts of this type at Harappa are identical in appearance to Sakesar chert and the INAA results indicate that, of the three regional sources compared, they are most geochemically analogous to samples of black-brown chert collected from the Nammal Gorge / Buri Khel area of the central Salt Range. Furthermore, this exact same macroscopic type of chert was being exploited by peoples living at several Early Harappan Kot Dijian Phase sites in the immediate vicinity of the Salt Range. INAA results suggest that tan-gray chert from the Rohri Hills of northern Sindh was being transported 500 km to Harappa as early as the Ravi Phase (Period 1) and continued to be acquired by the site's residents through at least the mid-urban phase (Period 3B). There is also some indication that examples of another type of tan-gray chert, which chemically resembles that occurring in the Mohmand Agency of northern Pakistan, *could* be present in Harappa's lithic assemblage. However, many more analyses of comparative source samples from the NWFP and northern Sindh are needed in order to determine if those indeed represent a different source or are just variants of Rohri Hills chert. The INAA results indicate that the single analyzed tan-gray chert blade fragment from Harappan Period levels at Nagwada in Gujarat was probably also derived from the Rohri Hills. This small but important piece of evidence, together with that results provided by the samples from Harappa, lends support to assertions that tan-gray chert from that specific part in northern

Sindh was being widely distributed across the Greater Indus region and beyond during the Harappan Phase of the Indus Tradition. Shortly before this book was being finalized, data were returned from the analysis of chert artifacts from Dholavira in Gujarat and Rakhigarhi in Haryana that confirmed the presence of Rohri Hills chert at those Indus cities. However, at Dholavira, just as at Harappa, it appears that alternate sources of tan-gray chert were used to a limited degree. Unlike at Harappa, however, residents of Dholavira also used a great deal (perhaps up to 50% of the lithic assemblage) of locally available microcrystalline silicates (mostly clear or milky semi-translucent chalcedony that occur at many places across Kutch) to produce blades and other tools.

Much of the tan-gray chert found at Indus Civilization settlements was probably transported to those sites in the form of finished, standardized long blades (Inizan and Lechevallier 1997). These were clearly produced on an enormous scale at Rohri Hills quarry/workshops dated to the Harappan Phase (Biagi and Cremaschi 1991; Biagi 1995). At Harappa, however, at least some chert evidently was acquired in unfinished form, probably as unworked, or perhaps marginally reduced (Figure 6.33), nodules. On average around six percent of the chert artifacts recovered at the site are wholly or partially composed of the cortex that forms on the exterior of such nodules (Figure 6.34 A). Over 80% of artifacts with cortex are flakes, which would indicate that nodules were being reduced at the site, as opposed to just blades with cortex, which could still have arrived at the site in finished form. When large-sized chert chunks and flakes with cortex from Harappa are directly compared with the Rohri Hills nodules collected for this study (Figure 6.34 B & C), the archaeological fragments are so similar visually that they appear as if they could have been struck directly from the geologic samples. Whole, unworked nodules, especially those from the northern tip of the Rohri Hills, would have been desired by makers of cubical stone weights as the most prominent banding occurs nearer the cortex. Nodules weighing 30 kg or more are not uncommon in that geologic formation (*personal observations* 2001). Transporting stones of that size over 500 km to Harappa easily could have been accomplished by means of bullock cart or river-craft. In Chapter 11, I show that limestone ringstones weighing more that 100 kg were likely being transported 800 km to the city from the northern Gujarat region during the latter part of Period 3.

What, ultimately, is most revealing about chert usage at Harappa is the way in which the variety of types decreased over time – from three main types plus several minor types during the Ravi Phase to the exclusive (or very nearly so) use of Rohri Hills chert during the Harappa Phase. This change cannot be explained by a diminishment of material acquisition networks stretching toward the Salt Range and beyond, as steatite (Chapter 7), vesuvianite-grossular (Chapter 9), alabaster (Chapter 10) and lead (Chapter 12) continued to be acquired from regions far to the north of Harappa during Period 3. That the shift to the use of one chert source/type occurred at the transition to Harappa's urban phase and appears to have been an extra-regional phenomenon is, no doubt, highly significant. Ratnagar concludes (2001a: 354) "that the distribution of [Rohri] chert blades reveals not trade according to variable regional demand but a regional distribution process handled by the rulers" of Indus society. That is certainly a possible explanation and one which I explore further in the discussion section of Chapter 13.

In the next chapter, I examine steatite – the single most abundant material variety in Harappa's rock and mineral assemblage.

# CHAPTER 7

# STEATITE ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: "STEATITE CIVILIZATION"

Steatite – a rock composed primarily of the mineral *talc* (hydrous magnesium silicate) in its massive form, was undoubtedly a material of tremendous importance at Harappa. Artifacts made from it comprise nearly 40% of the site's rock and mineral assemblage. This soft (Mohs ≈ 1 – 2.5), easily carvable stone was not only used for the mass-production of common items, notably the ubiquitous wafer-like disc bead (Figure 7.1 A) and the almost impossibly small "micro-bead" (note the human hair on which the bead in Figure 7.1 B is strung), but also for the closely controlled creation of objects with significant political and/or economic value such as stamp seals (Figure 7.1 C) and inscribed tablets (Figure 7.1 D). Steatite artifacts of one kind or another have been reported from practically every excavated Indus Civilization site. It has been observed that the aforementioned beads are so common that their presence alone could almost be considered a marker of a settlement's "Harappan" character (Vidale 1989c). The archaeometrist and renowned bead scholar Horace Beck even went as far as to characterize Indus society as a "steatite civilization" (cited in Vidale 2000: 59).

In terms of addressing the lines of inquiry outlined in Chapter 1, there are few rocks or minerals in Harappa's assemblage that hold as much promise as steatite (for a view to the contrary see Asthana 1993: 274). Sources of the stone are found in every major region surrounding the Indus Basin (Figure 7.2). However, in comparison to some of the other widespread rock varieties examined for this study (such as the different types of grindingstone, limestone and alabaster), occurrences of steatite tend to be much more geographically circumscribed within the regions where they are found. Steatite provenience data may, therefore, allow us to more precisely identify the region or regions with which Harappans were interacting (either directly or indirectly) when acquiring this material (Question 1). Furthermore, at different times during its development and existence, the Indus Civilization bordered numerous potential steatite source areas (Law 2002) and, at Harappa, the raw material is present in abundance throughout site's chronological sequence. This material sub-assemblage is, therefore, particularly well suited for examining diachronic change in inter-regional interaction networks (Question 2). Finally, the production of steatite objects was an activity that took place in each of Harappa's major habitation areas. In contrast to chert artifacts during the site's urban phase (Period 3), raw steatite exhibits a great deal of visual variability, which *could* indicate that multiple sources were used. This makes steatite a potentially excellent material for detecting intra-site variations in source area access that may be evidence of competition between residents of different parts of the site through the control of essential resources (Question 3). It is for all of the above reasons that I placed a great deal emphasis on the investigation of this variety of stone while conducting research for this book.

This chapter is an account of my attempt to systematically identify the geologic sources from which residents of Harappa and certain other Indus Tradition peoples acquired steatite. It is presented in four sections. The first begins with a brief overview of steatite use in the Indus Tradition. I

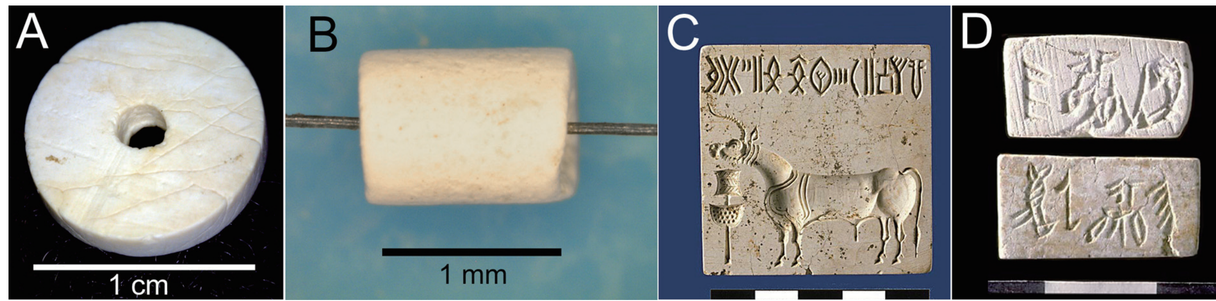



**Figure 7.1** Various types of steatite artifacts from Harappa.
**[A]** Disc bead. **[B]** Micro-bead. **[C]** Stamp seal. **[D]** Inscribed tablets.

then provide details regarding this material sub-assemblage at Harappa and relate which samples from it were selected for geologic provenience analysis. I also provide details on steatite artifacts from eight additional archaeological sites – Mohenjo-daro, Nausharo, Mehrgarh, Mitathal, Gola Dhoro, Nagwada, Tepe Hissar and an unknown site in the Loralai district of northern Balochistan, which I was very fortunate to have been able to include in this study. In the second section of this chapter, I highlight certain aspects related to the petrogenesis of steatite that are important for understanding where deposits of the stone occur and are also necessary for evaluating the geochemical data produced in the analysis of artifacts and source material. I then provide a detailed, region-by-region review of steatite occurrences in the Greater Indus region. In the third section, I present the results of a geologic provenience analysis the steatite artifacts. One hundred forty-one artifacts from Harappa, along with 38 artifacts from the eight additional sites were analyzed using instrumental neutron activation analysis (INAA). These were compared, using canonical discriminant analysis (CDA) and cluster analysis (CA), to data from 442 geologic samples collected from 37 individual deposits of steatite from around the Greater Indus region. The analyses provided results that were, in many ways, surprising. The source composition of the steatite assemblage at Harappa was far less variable, both synchronically and diachronically, than anticipated. It also became apparent that Indus Tradition craftspeople were, in general, using raw material from a very specific kind of geologic deposit. In the fourth and final section, I provide a summary and discuss the implications of the provenience study results. I also argue that technological-aesthetic considerations (the need for stone that would become white when heat-treated), rather than proximity to sources, dictated which deposits Harappans acquired steatite from. All sites, regions and sources discussed in this chapter are identified on Figure 7.2.

## STEATITE IN THE INDUS TRADITION

The first evidence for the use of steatite by Indus Tradition peoples goes back to the very earliest (ca. 7000 BC), pre-ceramic Neolithic levels (Period I) at Mehrgarh, where small cylindrical beads composed of black-colored steatite are present in an ornament assemblage predominantly made up of shell beads (Barthélémy de Saizieu and Bouquillon 1994: 47-48). The stone soon thereafter became the most abundantly utilized ornamental material at the site and it remained so throughout the long Neolithic/Chalcolithic sequence there and at nearby Nausharo (Barthélémy de Saizieu and Bouquillon 1997: Figure 1). During that time, there were numerous technological innovations involving steatite (documented in Barthélémy de Saizieu and Bouquillon 1994, 1997; Miller 1999; Vidale 1989a,

**Figure 7.2** Sites, regions, and steatite deposits discussed in this chapter.

2000); the most important of which was the heat-treatment of the stone to increase its hardness and change its color to white (this process is discussed in detail in the final section of this chapter). Indus Civilization craftspeople inherited these innovations and themselves produced new ones. The recovery of "talc-coated clay dishes" at Harappa likely indicates that they had become aware of steatite's heat-resistant (refractory) properties (Miller 1999: 419-422). In addition to the beads, seals and tablets mentioned in the chapter introduction, steatite was used to create a wide range of other items such as amulets, pendants, cubical weights, inlays, miniature vessels, figurines and small statues (including the famous "Priest-King"). Horace Beck wrote (1934: 69) that the steatite objects produced by Indus Civilization craftspeople were remarkable "not only in their number and variety, but also in their extreme beauty and perfection of execution."

## The steatite assemblage at Harappa and samples selected for this study

Roughly 22,000 steatite artifacts have been recovered at Harappa (precisely 21,872 have been tabulated to date but I say "roughly" because more are constantly being added to the total as large surface collections and micro-debitage samples are evaluated). About 80% of those are beads composed of heat-treated steatite or steatite-paste (Kenoyer 2005a: Table 2). The remaining 20% or so include all of the other items mentioned in the preceding section, unfinished objects (again mostly beads), manufacturing debris and pieces of unworked steatite. It is not necessary to provide a detailed breakdown of the spatial and temporal distribution of steatite artifacts at Harappa because, like chert artifacts, they are *everywhere*. They have been recovered (in abundance) in every excavation trench placed at the site and from secure contexts representing each of its chronological phases and sub-phases. This is not to say that the assemblage is completely uniform across time and space. The production of glazed steatite button seals, for instance, does not begin until Period 2 (Meadow and Kenoyer 2001) while incised steatite tablets do not appear until the middle of Period 3B (Meadow and Kenoyer 2000). Also, there is evidence that seals and tablets were only made and used in certain parts of the site (ibid.; Kenoyer 1992a). New styles of steatite beads emerged over time as new technologies were developed (Kenoyer 2005a). However, as a material variety, steatite was, in every sense of the word, *ubiquitous* at Harappa.

Out of the 22,000 steatite artifacts at Harappa, only around 3,000 (again roughly) have not been heat-treated. In the section on steatite in Chapter 4, I discussed the physical changes that result when stone of this variety is heated and I further elaborate on that process in the concluding section of this chapter. Although much less abundant, unheated (I will use the terms "unfired" and "raw" as well) steatite artifacts have also been recovered from each phase and in every part of the site (Figure 7.3). It is this

**Figure 7.3** Spatial and temporal distribution of 2990 unfired steatite artifacts at Harappa.

| Mound ↓ / *Period* → | *1* | *2* | *3A* | *3B* | *3C* | *4/5* | *surface & disturbed* | *total* |
|---|---|---|---|---|---|---|---|---|
| F | . | . | . | 13 | 63 | . | 20 | *96* |
| AB | 160 | 63 | 264 | 31 | 44 | 6 | 86 | *654* |
| E | . | 8 | 184 | 71 | 201 | . | 197 | *661* |
| ET | . | . | . | 13 | 979 | . | 453 | *1445* |
| cemetery & off mound | . | . | . | 4 | 103 | . | 27 | *134* |
| total | *160* | *71* | *448* | *132* | *1390* | *6* | *783* | ***2990*** |

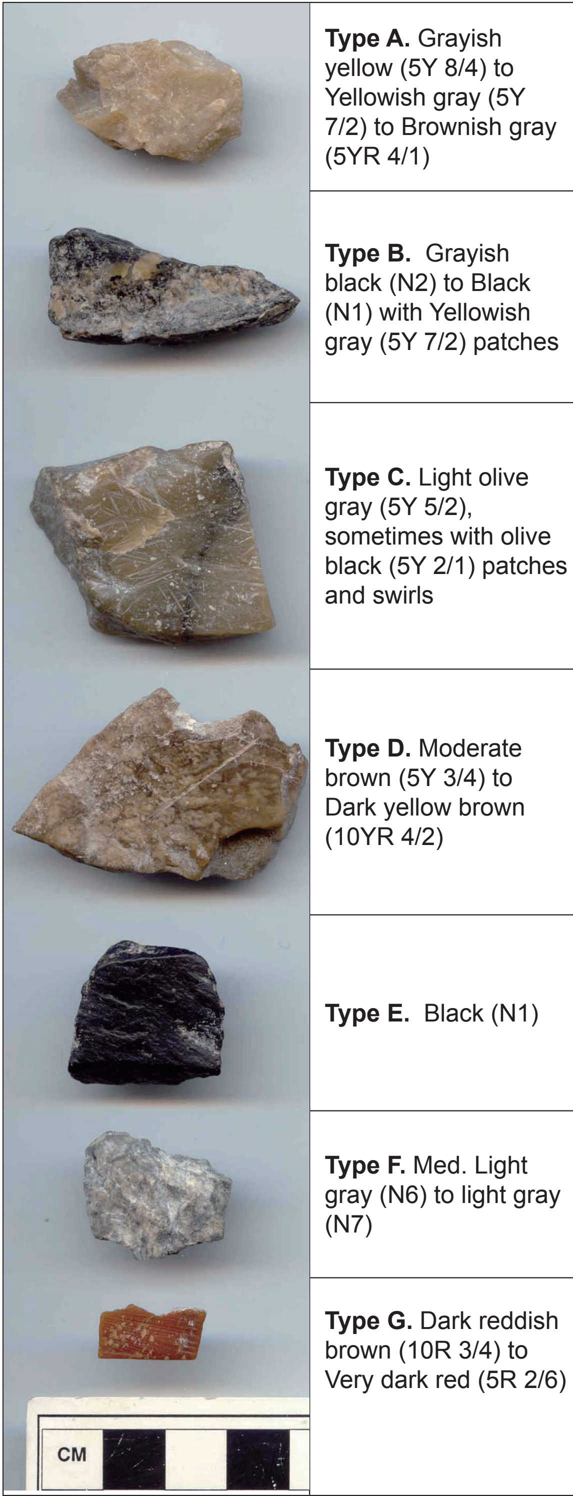



**Figure 7.4** Seven main macroscopic types of raw steatite at Harappa (descriptions made using a Munsell Rock-Color Chart).

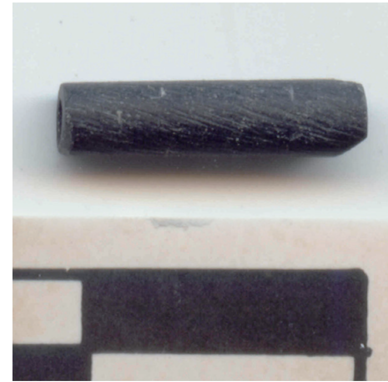
sub-assemblage that is best suited to be the subject of geologic provenience investigations as the original mineralogical structures of the artifacts in it are unmodified by heat.

It is clear from even a cursory inspection of the sub-assemblage of unfired steatite artifacts at Harappa that there are multiple, macroscopically distinct kinds of material within it. Massimo Vidale has speculated (2000: 56) that such variability (caused by secondary minerals in the rock) may be indicative of materials from different geologic deposits. Moffat and Buttler found (1986: 114) that visual comparisons of artifacts made from raw steatite to geologic samples was more effective (at least in their study area) than INAA in efforts to identify possible sources. For these reasons, it was deemed practical to create a macroscopic typology for unfired steatite at Harappa. This was undertaken using a Munsell Rock-Color Chart (Rock-Color Chart Committee 1995). Seven main macroscopic "types" of steatite were defined (Figure 7.4) after examining around 300 unfired steatite artifacts (roughly 10% of that material sub-assemblage) from surface collections and from secure contexts ranging from periods 1 through 5. As will most such typologies, the categories I created are highly subjective. They could be lumped together or split in any number of other ways. For instance, Type B might simply be an intermediate form between types E and A. Type G could be divided into several types as artifacts classified as belonging to it range from a dull muddy red brown to a deep red. Be that as it may, I would argue that these seven "types" represent very well the main visual variations exhibited by the raw steatite used at Harappa. Whether or not each is actually indicative of steatite from a different geologic source is something that was unclear when I created the typology, however. Although I examined only a portion of the sub-assemblage, there did not *seem* to be any temporal or spatial patterning in the distribution of the "types" that might suggest Harappans in different periods or parts of the sites used only certain "sources" (all types are represented on each mound and most types are present in each phase). Later, while conducting geologic field studies, I came to realize that the macroscopic appearance

**Figure 7.5** Special unfired steatite artifacts from Harappa analyzed for this study.



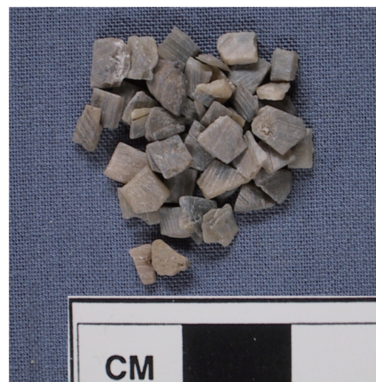

**A**. Three views of a broken, unfinished seal (H96/7257-46). Front (left image), sawn edge (middle), broken side (right)



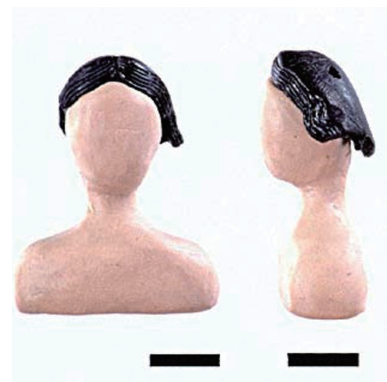
**B**. Cylindrical bead from Tr. 39, Mound AB (H96-7467-658)



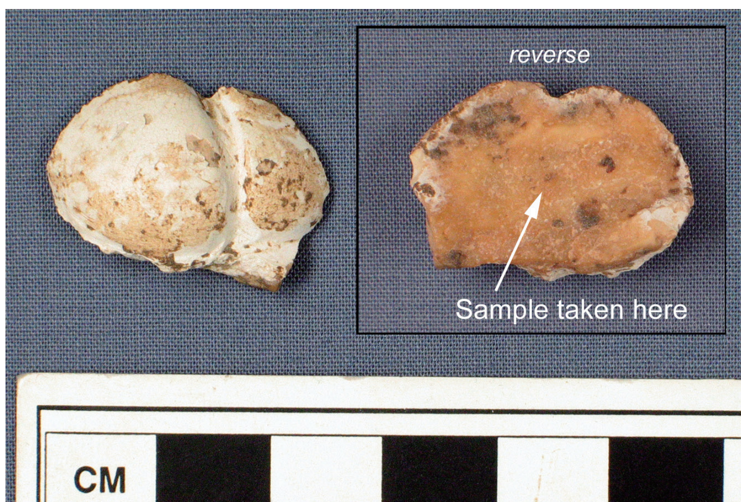

**C**. Disc bead blanks, Tr. 54, Mound E (H2000-2301-176)

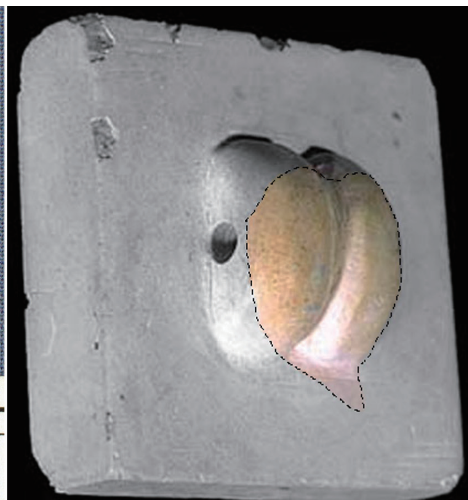



**D**. Disc bead blanks, Tr. 54, Mound E (H2000-2301-177)



**E**. Black wig (H98/8668-2) from Tr. 43, Mound F, Period 3C



**F**. Left - Front and reverse of a broken seal boss, Tr. 59, Mound E (H90/3208-68). Right - A reconstruction of the appearance of the boss prior to it breaking.

of steatite can be highly variable within a single deposit and even in an individual hand sample. It was becoming apparent that my typology might not end up having much utility in terms identifying the source of this type of stone. Still, I also observed that there are some highly distinctive and *recognizable* steatite varieties around the Greater Indus region (such as certain sub-varieties from the Las Bela area of Balochistan, which I have been able to identify on sight in jeweler's cases from Karachi to Rawalpindi).

I have, therefore, included the typology here and, later in the chapter, will be examining how it holds up against geologic provenience determinations made using INAA.

When selecting artifacts from Harappa's unfired steatite assemblage for geologic provenience studies, I tried to mainly choose from among the 700 or so fragments of *unmodified* stone recovered at the site; the reasons being, 1) I wanted to avoid subjecting any finished or semi-finished artifacts for destructive INAA whenever possible and, 2) I did not wish to damage any worked surface on examples of manufacturing debris. The study of saw marks on the latter artifact type has already provided valuable insights into the changing technological capabilities of Harappan beadmakers (Kenoyer 1997b). In the around three dozen instances when I did sample manufacturing debris (this was almost always when it was the only kind of raw steatite artifact available from a particular location and/or chronological context) great care was taken to avoid damaging any worked surface. In the end, 135 unmodified fragments or pieces of debris were sampled for this study.

In spite of my hesitation to sample finished or semi-finished objects, there were a few times when I could not pass on an opportunity to analyze a special artifact (Figure 7.5). The first of these is what appears to be an unfinished steatite stamp seal (H96/7257-46) that broke during the manufacturing process (Figure 7.5 A). It was recovered from a street deposit exposed in Trench 37 on Mound F and dates to Period 3B. The face of the seal had not yet been carved and there were still saw marks on its exterior edge. Using a drill with a fine tungsten carbide bit, I took a sample for analysis from the broken side of the seal.

I also analyzed a small cylindrical bead made of black steatite (Figure 7.5 B). This artifact (H96/7467-658) was recovered from a disturbed deposit in Trench 39 on Mound AB that contained mix debris from Period 2 and later levels.

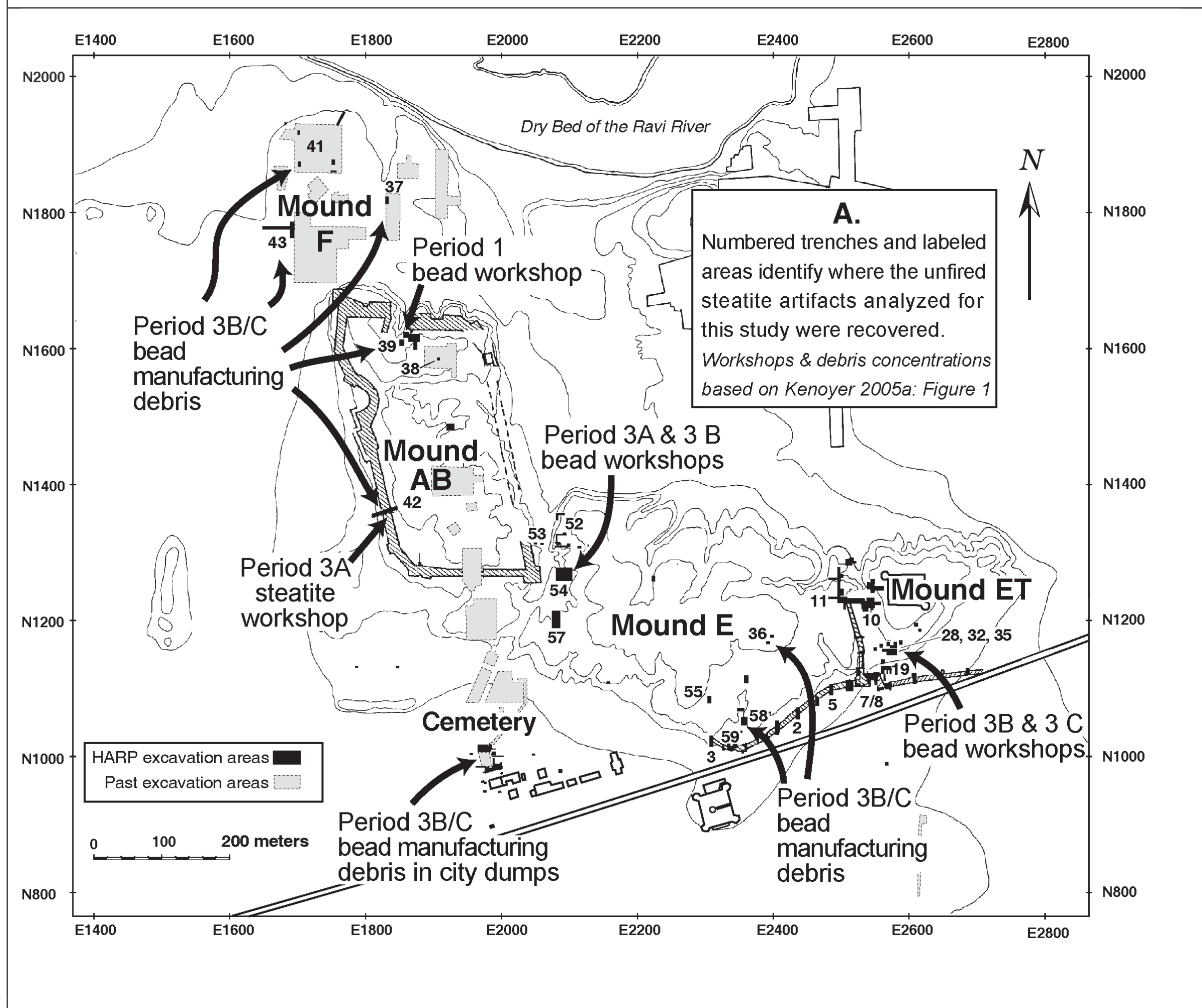
During the 2000 HARP field season, 177 tiny steatite bead blanks were recovered in an ashy debris layer in Trench 54 on the west side of Mound E (Meadow *et al* 2001: 14). They date to Period 3A and were likely dumped from one of the many workshops found in that area. It was quite exciting for me to analyze these particular artifacts as I was involved in the painstaking excavation and mapping of them. The bead blanks are composed of a steatite that is varying shades of grayish-yellow (Type B). A darker example (Figure 7.5 C) and a lighter example (Figure 7.5 D) were selected for analysis (H2000/2301-176 & 177).

A black steatite wig (H98/8668-2) that was likely part of small composite statue (the wig sits on a display bust in Figure 7.5 E) was recovered from later Period 3C levels in Trench 43 on Mound F. This artifact is identical to ones associated with the Bactria-Margiana Archaeological Complex (BMAC) of southern Central Asia and its recovery was an important new piece of evidence for Harappan interaction with peoples from that region (Meadow 2002). A tiny spur of material protruded from an area on the interior surface of wig, which Dr. Mark Kenoyer was able to carefully remove for analysis.

The final special artifact that I sampled was a portion (H90/3208-68) of a steatite seal *boss* (the perforated knob that is found on the reverse sides of most stamp seals) that had been recovered in Period 3C levels of Trench 59 on the southern side of Mound E (Figure 7.5 F *left*). Sometime prior to being excavated, probably during the Harappan Period, it broke from the seal to which it was originally a part of (see Figure 7.5 F *right* for a reconstruction what it probably looked like prior to breaking off) and the yellowish unfired or "raw" steatite that the seal was carved from is visible on the broken reverse side of the boss. A small sample of this unfired material was removed for analysis.

In the end, 141 unfired steatite artifacts recovered from Harappa were selected for geologic provenience analysis using INAA. Contextual and macroscopic type information for all artifacts in the set is

**Figure 7.6** Distribution of the unfired steatite artifacts from Harappa analyzed for this study.




B: Spatial and temporal distribution of the141 unfired steatite artifacts analyzed for this study.

| Mound ↓ / *Period* → | *1* | *2* | *3A* | *3B* | *3C* | *4/5* | *surface & disturbed* | *total* |
|---|---|---|---|---|---|---|---|---|
| F | *not present* | *not present* | *not present* | 2 | 13 | *none available* | *not sampled* | *15* |
| AB | 2 | 17 | 21 | 11 | 2 | 2 | 3 | *58* |
| E | *none available* | 1 | 2 | 7 | 16 | *none available* | 12 | *38* |
| ET | *not present* | *not present* | *not present* | 1 | 19 | *not sampled* | 4 | *24* |
| cemetery & off mound | *n/a* | *n/a* | *n/a* | *n/a* | 4 | *n/a* | 2 | *6* |
| **total sampled** | *2* | *18* | *23* | *21* | *54* | *2* | *21* | ***141*** |
| percent of total assemblage (see Figure 7.3) | 1.25% | 25.35% | 5.13% | 15.91% | 3.88% | 33.33% | 2.68% | **4.71%** |

listed in Appendix 7.1. Their spatial and temporal distributions are detailed in Figure 7.6. Although no formal strategy was employed in the selection process, an effort was made to assemble a set of samples that was representative of both the contexts where unfired steatite artifacts are found (which is to say all parts of the site and all of its chronological phases) and of the raw material itself (i.e., the seven main macroscopic "types"). I believe the effort was successful. Compare figures 7.3 and 7.6 B. Although the sampling of Period 2 was a bit heavy at the expense of Period 1, the temporal distribution of the set roughly mirrors that of the sub-assemblage. Likewise, the synchronic spatial distribution of the samples and the sub-assemblage correspond reasonably well with one another. In the set, there are 53 examples of Type A steatite, which is the most abundant type at the site and there are six examples of Type G, which is the rarest. The amounts of the other types fall in between, once again, much as they do in the assemblage.

Overall, the 141 artifacts selected for analysis represent a 4.71% sample of the unfired steatite sub-assemblage at Harappa. Importantly, many of the artifacts were recovered from contexts within or adjacent to bead workshops identified by the HARP. Most of the rest, although not clearly linked to workshops, were found among heavy concentrations of bead-making debris. These associations (see Kenoyer 2005a: Figure 1 and Figure 7.6 A above) strengthen our ability to use such artifacts to investigate questions regarding the control of resources and production by residents of different areas of the site.

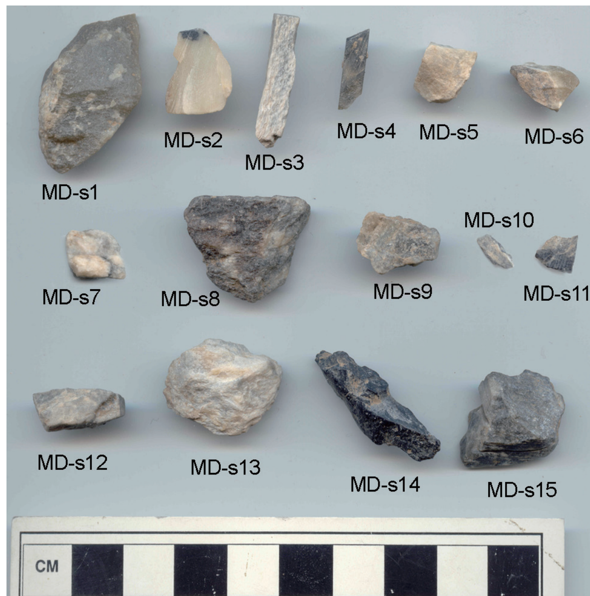
### Steatite samples from other prehistoric sites

I was fortunate to have been able to supplement the archaeological dataset with 38 unfired (or partially fired) steatite artifacts from eight other prehistoric sites in India, Pakistan and Iran (Figure 7.7). The inclusion of these samples has provided a more holistic picture of steatite acquisition networks in the Greater Indus region as well as a glimpse into what types of steatite people were using in areas sometimes far removed from Harappa.

Fifteen unfired steatite fragments (Figure 7.7 A) from the Indus city of Mohenjo-daro in Sindh were provided by Massimo Vidale (l'Istituto Italiano per l'Africa e l'Oriente [IsIAO], Rome) and Ghulam Mustafa Shar (Department of Archaeology, Shah Abdul Latif University, Khairpur). Both scholars have conducted extensive research at that site and jointly published an ethnoarchaeological study of steatite working in Balochistan and Sindh (Vidale and Shar 1990). All samples are surface finds collected during the mapping of craft activity areas. Although from non-secure contexts, they almost assuredly date to the site's Harappa Phase occupation (probably from the latter part of that phase). Samples MD-S7 through MD-S11 (Figure 7.7 A *middle row*) were recovered among various kinds of lapidary craft debris in the "Moneer" Area (Vidale 1987a, 1990). All others come from steatite-working areas discovered on the western side of area DK-A (Vidale 1987b, 1989c).

In the research collections of the Centre de Recherches Archéologiques Indus-Balochistan, Asie Centrale et Orientale at the Musée Guimet, Paris, there are a numerous steatite artifacts from the Neolithic/Chalcolithic settlement of Mehrgarh and the nearby (6 km southwest of Mehrgarh) Indus Civilization town of Nausharo. The sites are located at the foot of the Bolan Pass – a major route connecting the Indus Valley to the central Balochistan highlands and beyond to the Helmand Basin. Dr. Jean-François Jarrige, who directed excavations at both sites, graciously provided me with a set of unfired steatite artifacts for this study (Figure 7.7 B). The first seven of the 13 samples from Mehrgarh are black steatite bead roughouts (MR-s1 through MR-s3) and debris fragments (MR-s4 through MR-s7) recovered from a workshop (atelier) in area MR4 that dates to the early Chalcolithic Period (Mehrgarh IIB – ca. 5000 BC) (Jarrige 1981: 99). These artifacts and several

**Figure 7.7** Unfired steatite artifacts from other sites analyzed for this study.




**A.** Fragments from Mohenjo-daro (MD)




**B.** Artifacts from Mehrgarh (MR) and Nausharo (NS)




**C.** Sawn steatite from an unknown site in Loralai (LOR-s1)



**D.** Black steatite beads from an unknown site in Loralai (LOR-s2)




**E.** Steatite fragment from Nagwada (NGW-s1)



**F.** Two views of a broken unicorn seal from Gola Dhoro (GD-s1).




**G.** Sawn steatite fragments from Tepe Hissar (TH)




**Figure 7.8** A steatite seal fragment from the site of Mitathal, Bhiwani District, Haryana.

hundred more like them from the same deposit were the subject of studies aimed at reconstructing the steatite bead manufacturing process (Vanzetti and Vidale 1994; Vidale 1995). The remaining six samples from Mehrgarh include a debris fragment (MR-s8) and several small red, green and black steatite beads or bead fragments (MR-s9 through MR-s13) from Period I levels (ca. 7000 – 5500 BC). A single broken bead (NS-s1) from Nausharo rounds out the sample set. It is composed of a bright red steatite and dates to Nausharo Period III, which is roughly equivalent to Period 3B at Harappa.

In March of 2001, I met with Mr. Syed Ghani – an Assistant-Director at the Geology Survey of Pakistan-Quetta, in order to discuss the geology of the Loralai District of northern Balochistan, which was his research area as well as his native place. At that meeting, he showed me a box containing stone artifacts given to him by the local people of that area. Among the mostly chert blades were two kinds of steatite artifacts – a red steatite fragment that had been sawed on one end (Figure 7.7 C) and a group of tiny black steatite beads (Figure 7.7 D). He said he believed the artifacts were from a mound in the Loralai Valley but he could not tell me its name or precisely where it was. Having seen many artifacts like these before, I felt fairly certain that both were from the prehistoric period. The fragment, in particular, caught my attention. Although somewhat reminiscent of Type G steatite at Harappa, the patterning and unusually deep red color of the stone appeared to me to be identical to a material used to make a number of the stamp seals at Mohenjo-daro. Compare Figure 7.7 C to, for example, the seal pictured on the cover of Asko Parpola's book *Deciphering the Indus Script* (1994). Mr. Ghani kindly allowed me to remove a small piece from the sawn fragment and select a few of the black beads for this analysis.

Dr. Kuldeep Bhan (Department of Archaeology, Maharaja Sayajirao University, Baroda) provided two samples for this study from Indus Civilization settlements located in Gujarat. The first was a piece of light-green steatite (Figure 7.7 E) removed (by Dr. Bhan) from a large chunk of unworked material (Hegde *et al* 1990: 193; Sonawane 1992: 165) recovered in Harappan Period levels at the site of Nagwada, which is located on the western edge of the North Gujarat Plain. The second was a sample taken directly from a unicorn stamp seal discovered at Gola Dhoro (also known Bagasra) in the northern part of the Saurashtra Peninsula (Bhan *et al*. 2004). The seal (Figure 7.7 F *left*), which was one of five discovered at that very small (≈ 2 ha) walled settlement, had been

broken in antiquity and a zone of raw, greenish-grey steatite was exposed in its unfired interior (Figure 7.7 F *right*). Dr. Bhan was able to remove a small sliver of material from that area for analysis.

Also included in this study were four pieces of sawn steatite (Figure 7.7 G) collected (and again kindly provided) by Dr. Massimo Vidale from the surface of the Bronze Age site of Tepe Hissar (Schmidt 1937) in northern Iran (not shown on Figure 7.2). Numerous craft activities, including steatite working, have been documented at this site (Bulgarelli 1979; Tosi 1989), which exhibits limited evidence of long-distance contact with the Greater Indus region (Chakrabarti 1990: 7-8; Heskel 1984). Analysis of the fragments provides a way to compare Harappan steatite to raw material that was (presumably) acquired from geologic sources in that distant region (over 2000 km northwest of Harappa).

Lastly, a sample of unfired steatite was taken from the broken section of a rectangular seal fragment (Figure 7.8) recovered during a recent surface reconnaissance (Prabhakar *et al*. 2010) at the site of Mitathal, Bhiwani District, Haryana. Seals of this shape date to the later part of the Harappan Period, which is the equivalent of Period 3C and Harappa (ca. 2200 to 1900 BC).

Now that I have presented the set of 179 (141 from Harappa and 38 from elsewhere) archaeological steatite samples assembled for this provenience study, the next step is to outline and discuss the geologic sources to which they are (and are not) be compared.

## IDENTIFYING POTENTIAL STEATITE SOURCES FOR INDUS TRADITION PEOPLES

Dr. Mark Kenoyer has argued that "one important factor in the development and expansion of Indus trade networks is that many essential raw materials needed by the Indus cities were available in more than one locality" (Kenoyer 1998: 91). With regard to steatite – a raw material which the need for and the trade in was evidently "continuous and massive" (Vidale 2000: 58) – craftspeople and consumers at Indus cities would have quite possibly depended on having access to stone from multiple sources. Beginning with Sir Edwin Pascoe, who wrote the chapter entitled "Minerals and Metals" (Pascoe 1931) for the first Mohenjo-daro site report (Marshall 1931b), there has been a great deal of speculation by researchers about exactly where those sources might have been located (Asthana 1993: 274; Biwas 1996: 47; Fentress 1976: 306; Kenoyer 1998: 93; Lahiri 1992; Law 2002; Ratnagar 2004: 166-167; Shaikh 1987: 72; Thapar 1993: 11; Vidale 2000: 58). Some of the more recent speculation is well informed while some is merely a rehash of what Pascoe wrote 75 years ago. For this study, it was crucial to have an accurate and comprehensive knowledge of where steatite was available to Harappans in the Greater Indus region and to obtain samples for provenience analyses from as many of those sources as possible.

In this section, I first discuss the petrogenesis of steatite. This is helpful not only for understanding where deposits of this stone tend to be found but is it also necessary for evaluating the results of the geologic provenience analysis presented in the section that follows this one. I then say a brief word about the sampling of the steatite sources for this study. The bulk of this section is devoted to detailing where steatite *of the quality* that Harappans used occurs in the Greater Indus region and, importantly, where it does not.

### Steatite petrogenesis

Steatite is called *soapstone* or *potstone* in the West and *zahr muhra*, *silkhari* or *ghia pattr* in South Asia. Some archaeologists (especially those working Arabia, Iran and West Asia) prefer to use the term "softstone" for steatite, chlorite, serpentine and other carvable rocks with a low Mohs hardness. This

**Figure 7.9** A summary of the petrogenesis and character of steatite.

**Steatite** is a rock
composed primarily of the mineral
**talc** (hydrous magnesium silicate).

It may form in either ...




*Muslimbagh ophiolite sequence*

or




*Khyber Dolomite*

The result can be ...



*Urgasai Nasir (ZUN) steatite*

visually
identical
steatite




*Prang Dera (LKPD) steatite*

... with very **different trace element characteristics**
that reflect their respective parent-rock formations.

is understandable; particularly with regard to the materials just mentioned as they can closely resemble one another and, in certain geologic settings, co-occur in the same stone. However, I have avoided using the term here because it is simply too vague. Steatite is a rock composed predominantly of talc. XRD analyses (Appendix 4.1) have clearly shown that this is the variety of stone Harappans were using.

The mineral talc ($Mg_3Si_4O_{10}(OH)_2$) forms when magnesium-rich rocks are altered by low-grade stress, heat or hydrothermal action (Deer *et al.*1992: 330). "Talcose" rocks thus tend to occur at or near tectonic plate boundaries, in ophiolite zones (areas where plate tectonics have uplifted and emplaced large fragments of oceanic crust onto a continental landmass) or other areas where metamorphic processes have acted upon a suitable parent-rock. There are two kinds of parent-rocks suitable for the formation

of talc. The first are *ultramafic* (high magnesium - low silica) igneous rocks. These include (but are not limited to) peridotites, dunites, pyroxenes and serpentinites, which are common in oceanic crust and, thus, the reason why steatite bodies sometimes develop in ophiolites. The second kind are calcareous sedimentary rocks (usually limestones but also some mudstones) that have had their calcite ($CaCO_3$) component converted to calcium magnesium carbonate ($CaMg(CO_3)_2$) in a process called *dolomitization* (Blatt 1992: 312). *Dolomite*, *dolostone*, *dolomitic limestone* and *magnesium limestone* are all terms used to refer to this type of rock.

Owing to its diverse geologic origins, steatite may contain, in addition to talc, any number of a wide variety of accessory minerals. Using XRD, Vidale and Bianchetti (1997) identified *dolomite* and *quartz* in steatite samples from Harappa (as did I – see appendices 4.1, 4.2 B and 4.2 C), *calcite* in a sample from Mehrgarh and *magnetite* and *clinochrysotile* in samples obtained from a modern craftsman. Barthélémy de Saizieu and Bouquillon (1994: 51) detected *anthophyllite* in steatite beads from Mehrgarh. Chlorite, serpentine and chromite are other accessory minerals that may be found in steatite. Vidale expressed (2000: 59) hope that XRD could be used to address questions of provenience by identifying mineralogical sub-groups within the steatite found at Indus sites and, to a certain extent, it can. Steatite containing dolomite is clearly of dolomitic origin. Magnetite is an extremely common constituent of igneous rocks (particularly serpentinezed peridotites and dunites) and, when detected, probably indicates steatite of ultramafic origin. With such knowledge one can focus on or exclude certain types of geologic formations as potential sources (e.g., there no need to go looking in ophiolites for the sources of steatite containing dolomite as an accessory mineral). However, XRD, at best, can really only take you that far. Accessory minerals are often present in amounts too low to be detected by XRD (note that only talc was detected in 20 of the 29 X-rayed samples from Harappa – Appendix 4.1).

Chemically pure talc is white. It is accessory minerals (detectable by XRD or otherwise) in the stone that provide steatite with its highly variable range of colors and patterns (recall Figure 7.4). Visual appearance could conceivably help to identify steatite artifacts from specific sources, provided that it is distinctive enough. For instance, among the modern samples that Vidale and Bianchetti analyzed (1997) was green steatite with prominent black spots. Vidale obtained this sample from a craftsman in Khairpur who himself had acquired it at the shrine of Shah Noorani in southern Balochistan (Vidale and Shar 1990). The stone actually occurs in the nearby Las Bela ophiolite (discussed below). In my experience, no other steatite with the exact same visual characteristics can be found elsewhere the Greater Indus region. It is used to make distinctive pendants and rosaries that are traded widely throughout Pakistan. Wherever I have encountered such stone in the *kabat* (portable display case) of a *johri* (professional stone seller), it was always attributed to Shah Noorani. Most steatite is not as visually distinctive as this, however. Moreover, the appearance of material within a single deposit can be highly variable. I have visited many deposits that contain stone resembling most of the macroscopic types present at Harappa. Also, the kind of parent-rock that steatite forms in does not necessarily endow it with a certain range of colors or patterns. I have collected samples from deposits of both dolomitic and ultramafic origin that, macroscopically, are indistinguishably from one another.

Ultimately, it is studies focusing on trace elements in steatite artifacts, rather than on mineralogy or visual appearance, that hold the most promise for determining their geologic provenience. Ultramafic rocks contain high concentrations of transition metals like chromium, cobalt and nickel (Dann 1988: 23). Truncer and others (1998) found that steatite deposits

of ultramafic parentage could be differentiated using this class of elements. Dolomitic limestones have lower concentrations of transition metals and often exhibit unique rare-earth element (REE) characteristics (Miura and Kawabe 2000). This may allow dolomitic steatite deposits to be differentiated from ultramafic ones and from one another.

Figure 7.8 is a graphical summary of the main points of this section.

### Sampling geologic sources

The geologic literature for South Asia contains references to hundreds of steatite deposits in the highlands adjoining the Indus Basin (in reality, of course, there are likely thousands). Obtaining a reasonable sample of the range of sources that were potentially available to Harappans may seem like an impossible task because of this. However, steatite in South Asia is unevenly distributed. The lion's shares of reported occurrences are in Rajasthan, in particular, southern Rajasthan. There are only, perhaps, four dozen or so *recorded* deposits elsewhere in the Greater Indus region. My regional sampling strategy was, thus, fairly straightforward – collect samples from as many recorded deposits in Pakistan, northern India and Gujarat as I could possibly to get to (and hopefully locate some unrecorded ones in the process) and then selectively sample occurrences in Rajasthan.

The sampling of an individual steatite occurrence typically involved walking along a zone of mineralization or across the breadth of a quarry and collecting the full range of the macroscopic types of *Harappan-quality* material present there. Steatite used by Harappans was, regardless of its color, patterning or mineralogy, almost always a very compact, physically homogenous stone. Materials from many of the deposits reported throughout the Greater Indus region, although perfectly suitable for modern industrial uses (Chatterjee 1978), would not have passed muster with Harappan seal-carvers or bead-makers because they were too impure (making them difficult to carve and saw) and/or their structure was too foliated (causing them to flake or split during manufacture or use). Not all of the nearly 60 locations I visited for this study contained Harappan-quality steatite. In the end, suitable samples from 37 different sources (18 in Rajasthan and 19 from elsewhere) were obtained.

### Steatite occurrences of the Greater Indus region

Before we begin the overview of steatite occurrences, please refer to the map of the Greater Indus region found near the start of this chapter (Figure 7.2). Marked on it are the geologic sources and archaeological sites that are discussed in this section. Labeled ellipses indicate areas where multiple deposits were sampled. Detail maps (figures 7.10, 7.15 and 7.22 A to D) for those areas are provided throughout this section. Note that different types of symbols mark the sources and sites shown on the various figures. These maps and the symbols on them serve as the keys for the scatterplots used in next section of this chapter. On some maps deposits are labeled with a two-to-four letter source code. The full source names for those codes is provided in text but can also be found in Appendix 7.2, along with other locational (region, district/agency, geographic coordinates) and geologic (parent-rock type) information pertaining to the steatite sources sampled for this study. Marked with blue circles and/or labeled in blue are locations or regions that I discuss, but for which steatite samples were not analyzed. The reason for this was either 1) I was unable to visit the area; 2) the steatite at the location was of a very low-grade and not at all of the quality that Harappans used; or 3) steatite did not actually occur there as reported.

Refer again to Figure 7.2. We begin this overview in southern Balochistan and then move clockwise around the highlands surrounding the Indus Basin – first going through northern Balochistan and then

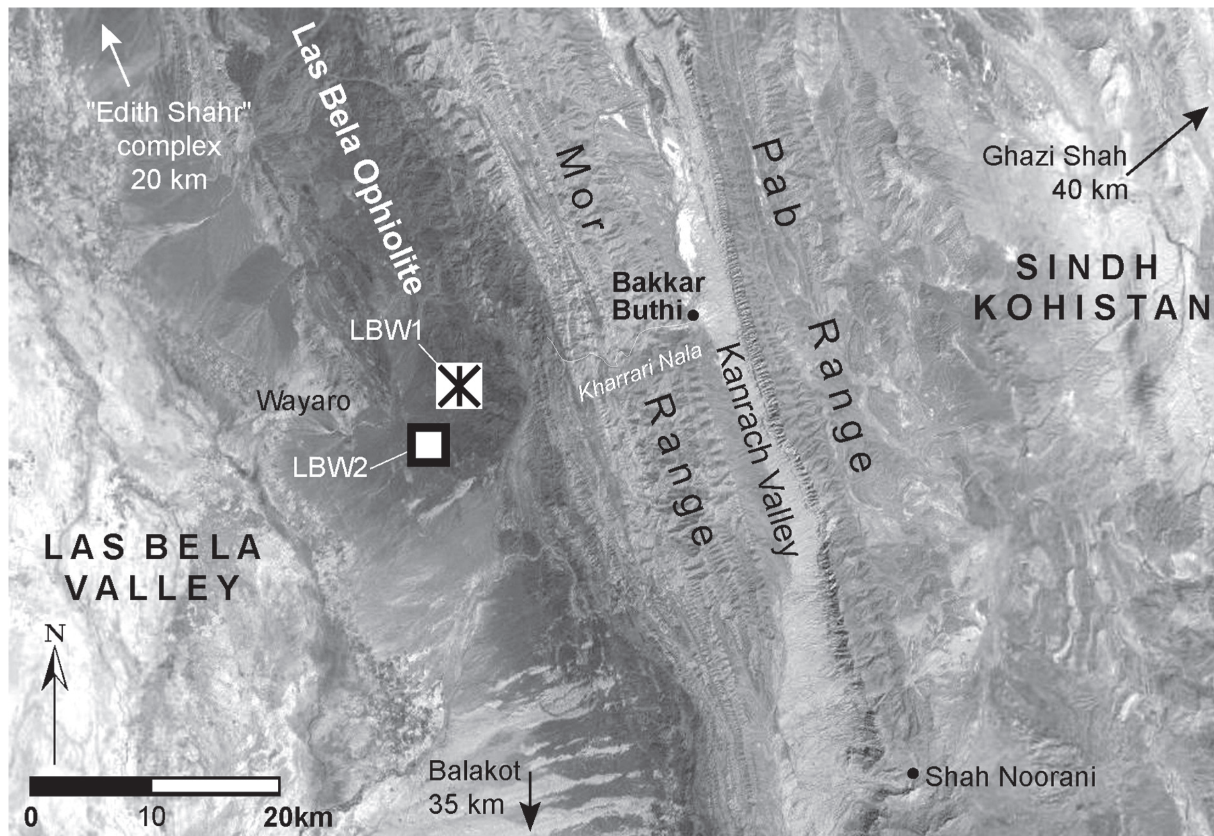



**Figure 7.10** Sites, shrines and steatite sources in and around the Las Bela Ophiolite, Las Bela District, Balochistan.

on to the NWFP and Pakistan's Northern Areas. We then turn southeast to follow the Himalayas for 600 km. After that that point we jump across the Gangetic Plain to the Aravalli Range of Rajasthan and follow it from the northern to the southern part of that state. Our tour of steatite occurrences will end in Gujarat.

***Steatite occurrences in Balochistan***

*- Las Bela District*

Steatite occurs at a few places in the Las Bela District of southeastern Balochistan. Prior to sampling those deposits, I had not encountered any reference to them in either the geologic or historical literature. I only located them because I wished to visit the shrine of the Sufi saint Shah Bilawal Noorani (or just Shah Noorani), which I had first learned about in Vidale and Shar's study (1990) of traditional soapstone crafts in Sindh. According to a johri/steatite-carver they interviewed named Ashiq Hussain, the shrine was the place where he had learned his craft and to where he traveled annually to attend the *mela* (festival) for the saint. It was also where he replenished his steatite stocks as it was in the "land of zahr muhra" (ibid.). Steatite could be acquired from local Mengal tribesmen who transported the stone to the shrine from sources that were a two or three-day walk away.

In Vidale and Shar's 1990 study, Shah Noorani is described as being in the Makran District, near the modern town of Turbat and the prehistoric sites of Shahi Tump and Miri Qalat (Besenval 2005). However, I could not locate it on maps or in the gazetteer for that district. Moreover, there were no geological formations in the region that could have hosted steatite deposits (there are ophiolites in the Iranian Makran, however). I learned from a johri in Karachi that, in actuality, Shah Noorani lies some 400 km to the east of the Turbat area in the Las Bela District near the Balochistan-Sindh border (Figure 7.10). Mention is made of the shrine in the *Gazetteer of Las Bela* (1907: 38). You can catch a bus from Lee

**Figure 7.11 A** The Shrine of Shah Bilawal Noorani (Shah Noorani) is located within this oasis-like nala in the southern Pab Range, Las Bela District, Balochistan.



**Figure 7.11 B** Johris at Shah Noori.



**Figure 7.11 C** Prayer beads carved from Wayaro area steatite.



Market in Karachi and be there in just under six hours. I visited Shah Noorani (Figure 7.11 A) in May of 2001 and met with the johri/steatite-carvers there (Figure 7.11 B) who showed me their wares (Figure 7.11 C) and informed me that the actual sources of zahr muhra were in the Wayaro area, about 45 km to the northwest. This placed them squarely in the middle of the Las Bela ophiolite – a geologic formation that could undoubtedly host steatite deposits (as well as the chlorite and serpentine that the Shah Noorani johris are also known for carving and selling).

Later the same month, I visited the Wayaro area (Figure 7.10) with Khawar Akhbar of the Geological Survey of Pakistan–Karachi. With the help of a

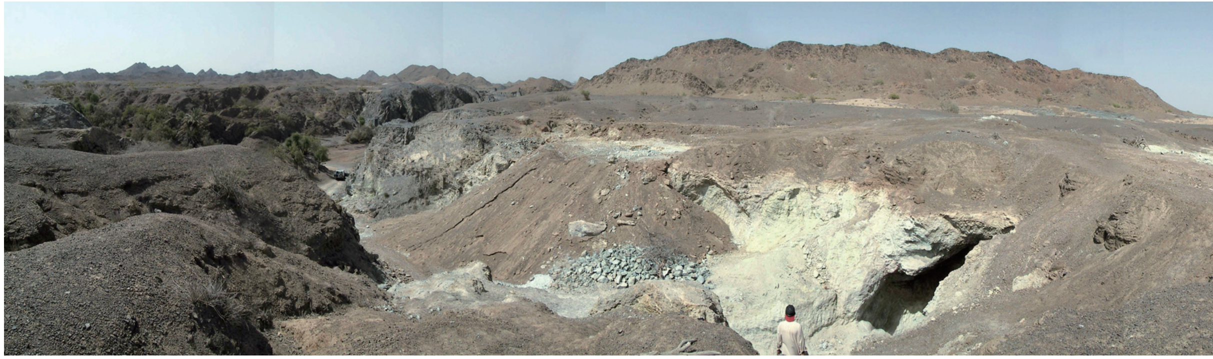


**Figure 7.12** Duddo steatite mine (LBW1), Wayaro area, Las Bela District, Balochistan



**Figure 7.13** Thaddi steatite mine (LBW2), Wayaro area, Las Bela District, Balochistan

local man we located and sampled two active mines (Figures 7.12 and 7.13) at locations called Duddo (LBW1) and Thaddi (LBW2), which were about 5 km apart. Throughout the area there were pits and shear zones from which steatite appeared to have been removed long before. We found no artifacts to provide us with an indication of when exactly that might have been, however, and our guide did not know of any mounds or other evidence of old settlements in the immediate area. This came as no surprise. Ophiolite zones are notorious for being lifeless, moon-like landscapes (Dann 1988: xi) and the area around the Wayaro deposits was no different.

Prehistoric settlements were not a great distance away, however, in any direction. Bakkar Buthi, which was occupied by Indus Civilization peoples for a period of time (Franke-Vogt *et al*. 2000), lies less than 20 km away on the other side of the Mor Range in the central Kanrach Valley. The Wayaro steatite sources could easily be reached from there via Kharrari Nala, which transects the range at that point. The site of Balakot, which has Early Harappan and Harappan phase occupations (Dales 1974), is situated some 60 km due south of the Wayaro area. All across southeastern Balochistan and into Sindh Kohistan sites belonging to the Early Harappan Nal and later Kulli phases are found (Fairservis 1975: 185-216). The so-called "Edith-Shahr" complex (ibid.) is just to the north at the head of the Las Bela Valley. On the other side of the mountains of Sindh Kohistan lie Amri (Casal 1961), Ghazi Shah (Flam 1993a) and other Early Harappan / Harappan Period sites.

My reason for highlighting the proximity of other prehistoric sites to the Wayaro deposits was to emphasize their importance as *potential* sources of steatite for Early Harappan and Harappan phase peoples. In simple terms of physical distance between a known Indus Civilization site and a deposit of high-quality (or any quality for that matter) steatite there are no closer sources. Moreover, I show in Chapter




**Figure 7.14** **[A]** Collecting Shah Noorani/Wayaro steatite. **[B]** Shah Noorani steatite beads for sale in Khairpur, Sindh. **[C]** A bead from Balakot that appears to be made from Wayaro steatite.

12 that lead ore at Harappa and Mohenjo-daro may have been acquired from deposits of that metal in the Kanrach Valley. For consumers in Sindh in particular, the Wayaro area of southern Balochistan *could* have been a very important source of steatite. Deposits there, although fewer in number, are over three times as close to Mohenjo-daro as those in Rajasthan, which has long been argued (Pascoe 1931: 679) to have been a major source of steatite for residents of that site. Most importantly, Early Harappans and Harappans were indisputably present in southern Balochistan and so the interaction networks through which steatite could have been brought to the Indus Valley were in place. Evidence that Harappans interacted with the peoples of Rajasthan, although it exists (Misra 1995, 1997), is much more tenuous.

One thing regarding these deposits gave me pause, however. As I mentioned above, Shah Noorani steatite (from the Wayaro deposits - Figure 7.14 A) has a very distinctive appearance. I had seen it on sale (Figure 7.14 B) across Pakistan but had only documented what I thought was the material at a single prehistoric site – Balakot, which is not surprising as that settlement is relatively close to the deposits. A small unfired bead (Figure 7.14 C) from that site composed of green steatite with black spots is in collections of the Department of Archaeology and Museum's Excavation Branch in Karachi. Nothing like it, however, is in the unfired steatite assemblage at Harappa or among the unfired artifacts from other sites that I have examined or seen photographs of. True, there are other macroscopic types of steatite at the Wayaro deposits. Perhaps Harappans were mining those instead. Or, perhaps, every single piece of this

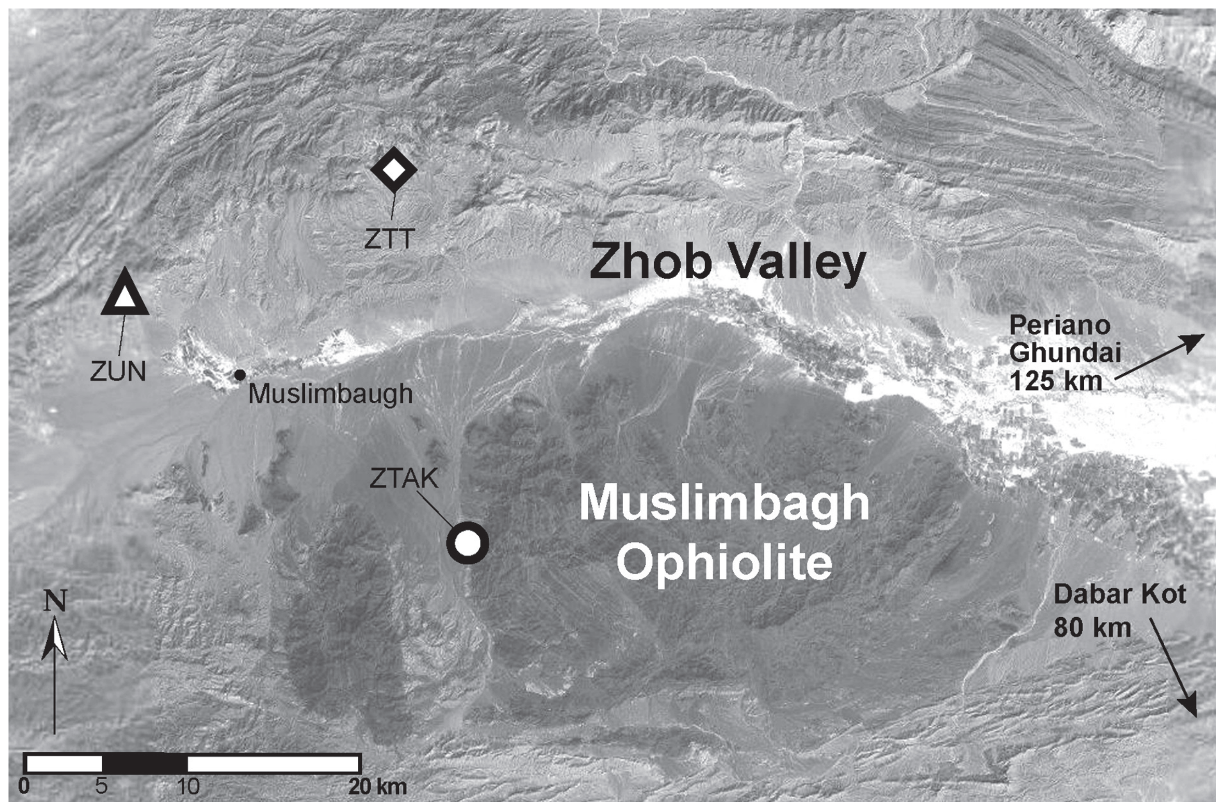



**Figure 7.15** Steatite deposits of the Muslimbagh Ophiolite, southern Zhob District, Balochistan.

kind of steatite at Indus sites has been heat-treated, thus obscuring the original the appearance of stone. I have doubts about the latter possibility, however. Whatever the case actually is, a statement like Louis Flam's (1981: 168) – that the source of steatite for the Early Harappan peoples of southern Sindh (Amri Phase) "can be supposed to have been southeastern Iran," is now clearly untenable.

*- Kalat District*

Moving northward now to the Kalat District of central Balochistan, Tariq and others reported (1998: 16) a 7 to 12 cm thick vein of light-grey soapstone in the lower shale member of the Shirinab Formation near the village of Chuttock. At just over 90 km to the west-northwest, this is the closest reported steatite occurrence to the sites of Mehrgarh and Nausharo. Unfortunately, I only learned of this occurrence after my Balochistan fieldwork was completed and so no samples from it could be included in this study.

*- Zhob District*

Continuing on to northern Balochistan, Ahmad noted (1969: Figure 30, #9) soapstone in the southwest part of the Zhob District but provided no further details on the occurrence(s). Fortunately for me, the region was the research area of Dr. Khalid Mahmood of Center of Excellence in Mineralogy, University of Balochistan-Quetta. He was able to lead me to and assist me in the sampling of high-quality steatite deposits at three locations in the Muslimbagh ophiolite (Figure 7.15). The occurrence at Takhahen (ZTAK) in the main body of the ophiolite provides a good illustration of how, whenever possible, I approached sample collection. The zone of talc materialization there runs intermittently along a 2-km long north-south strike (Figure 7.16). Samples (n ≈ 50 total) were acquired from three points along the zone where the best quality material could be found (Figure 7.17, points 1, 2 & 3). The zone was treated a single deposit as it essentially occurs in the same block of *harzburgite* (a peridotitic rock). Samples were also



**Figure 7.16** Direction of talc mineralization (looking north) at Takhahen in the Muslimbagh Ophiolite, Zhob, Balochistan

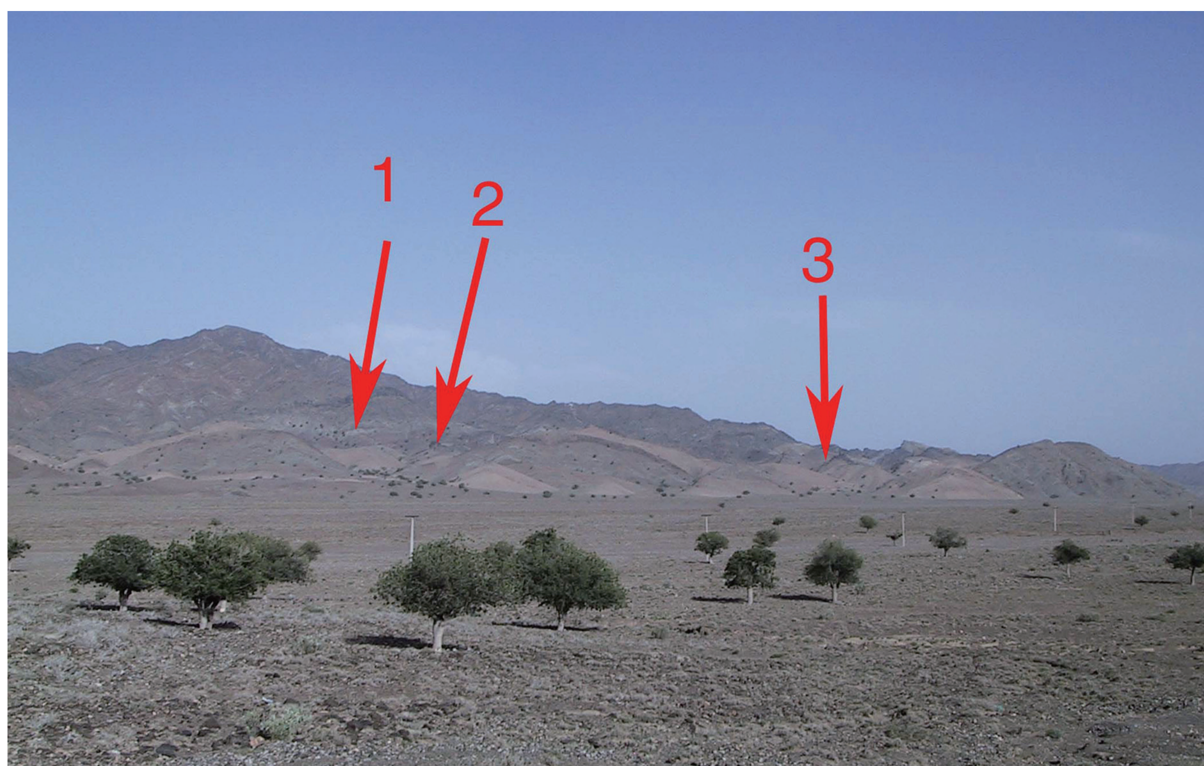



**Figure 7.17** Points sampled along the zone of talc mineralization at Takhahen.

collected in this way from fragments of ophiolitic rock containing steatite on the opposite side of the Zhob Valley, to the north of Muslimbagh town at Urgasai Nasir (ZUN) and Tor Tangi (ZTT).

The Muslimbagh ophiolite steatite deposits would have been the ones most accessible (≈ 80 to 120 km distant) to the prehistoric peoples of the Loralai District. For this reason, they are the best candidates for the sources of the sawn steatite and black beads (Figure 7.7 C & D) in archaeological sample set said to be from a mound in that area. I have represented those two samples on Figure 7.2 using a red plus ("+"

for the sawn fragment) and a red circle ("O" for the beads). Steatite from the Muslimbagh ophiolite could have been accessible to residents of Harappa during the urban phase as there was a clear Indus Civilization presence in the Loralai region at the sites of Dabar Kot and nearby Duki Mound (Fairservis 1975: 149).

From Muslimbaugh, the Zhob Valley arcs north-northeast and terminates near the border with the NWFP. Soapstone or talc is reported at several locations around this region (Heron and Crookshank 1954: 138; Pithawalla 1952: 202), which evidently was a key zone of interaction between the northern Balochistan highlands and the Indus Valley during the first half of the third millennium BC. At the northern end of the Zhob Valley sits the site of Periano Ghundai. A strong Early Harappan Kot Dijian presence is documented there (Mughal 1970: 217-221) alongside the site's highland "Zhob culture" material assemblage. Clusters of Early Harappan and Harappan Period sites (Dani 1971; Durrani 1988; Khan *et al*. 2000; Mughal *et al*. 1996) are found where the rivers draining northern Balochistan meet the Gomal Plain / Derajat region of the western Indus Valley. Ceramic parallels as well as finds of "Zhob mother goddess" figurines indicate that peoples from at least one of these plains sites – Dhera, had very close ties with the adjacent highlands (Siddique 1996).

Pockets of ultramafic rock dominated by the Zhob ophiolite are found in the northern Zhob region (all within about 50 km of Periano Ghundai) and "veins of up to a foot or so in thickness of white steatite" have been reported to occur in them (Heron and Crookshank 1954: 138). I visited two reported locations with Dr. Khalid Mahmood. An afternoon of searching the area "east of the 22nd milestone on the Ft. Sandeman-Gul Kach road" (ibid.), which is in the main body of the Zhob ophiolite, yielded only serpentine and chlorite. The local people around had no knowledge of any soapstone occurrence or any former mining operation. At Wulgai Oba (ibid.), we found only thin seams of very low grade talcose stone in what turned out to be dolomitic slates rather than ultramafic rock. We forewent a visit to a third reported soapstone occurrence on the road to Shinghar as the deposit was said to consist of only small talc "veins, which have been worked by local inhabitants for whitewash paint" (Huntington Survey Corporation 1960: 500).

It is very possible that there are occurrences of talcose stone in northern Zhob that Dr. Mahmood and I failed to locate (particularly in the Zhob ophiolite) during our limited period of fieldwork in that region. However, from what we observed it appears likely that there are no occurrences of Harappan-quality steatite in this region.

### *Steatite occurrences in the NWFP, FATA and Northern Areas*

*- Kurram Agency*

Beds of high quality steatite occur within the siliceous dolomite of the Safed Koh Range, which forms the Kurram Agency's northern border with Afghanistan (Badshah 1983; Bender 1995b: 273). Mian Sayed Badshah of the Federally Administered Tribal Areas Development Corporation (FATADC) organized a sampling expedition to this area for me in August of 2001. The steatite deposit (source code PD) that was visited (Figure 7.18) is located around 20 km northwest of Parachinar town in the Daradar Valley (an offshoot of the Kurram Valley) at an elevation of approximately 3000 meters. A larger, slightly higher deposit along Kharwala Nala in the western part of the range (Meissner 1975: 18; Ahmad 1969: 155) unfortunately could not be visited because of security concerns.

Elevation and steep terrain has limited exploitation of the Safed Koh steatite deposits in modern times. Whether or not the same would have been true during the Indus period is unclear. It is reasonable to believe, however, that Harappans might have had access to the Safed Koh and its resources. There is the ever present issue of "how did Harappans



**Figure 7.18** Sampling expedition to the upper Daradar Valley steatite deposit, Safed Koh Range, Kurram Agency, FATA.

get to and from Shortughaï in northern Afghanistan?" Passage through the Kurram Valley offers the most direct route from the Punjab to central Afghanistan and, from there, to the north. Its use as a thoroughfare for caravans and invading armies rivals and, perhaps, even surpasses that of the more famous Khyber Pass to the north (Markham 1879: 47-50). Although no prehistoric sites have been discovered in the Kurram Valley itself, the Kurram River passes the south flank of the Safed Koh Range and flows southeast into the Bannu Basin, where there was a strong Kot Dijian presence that was evidently sustained through a "Late"

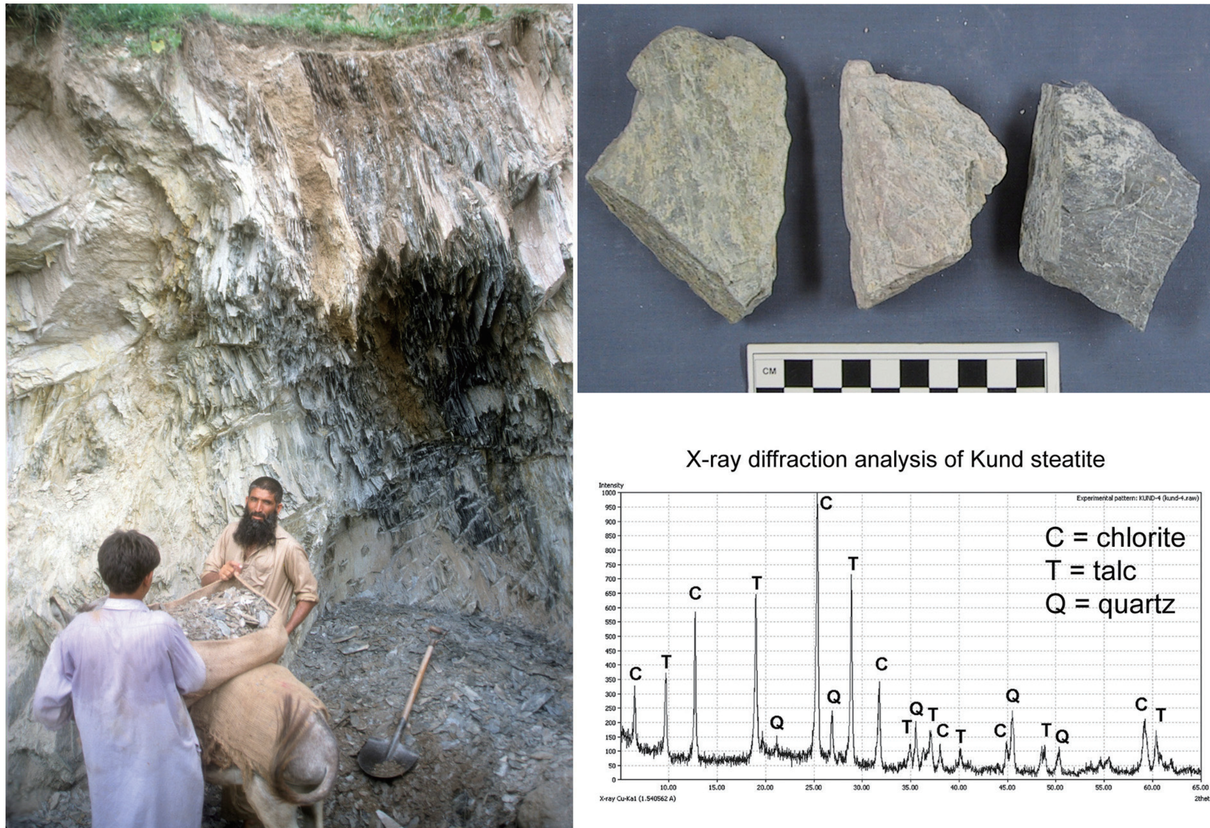



**Figure 7.19** Sampling and X-ray diffraction analysis of the Kund steatite deposit.

Kot Dijian phase concurrent with the Harappan Period (Khan *et al.* 1988, 1991a, 2002a).

*- Khyber Agency*

Ahmad reported (1969: 154) that steatite occurs in dolomite around the Landi Kotal area of the Khyber Agency but did not provide a deposit name or an exact location. After a visit to the agency headquarters in Landi Kotal town in December of 2000, I learned that the stone could be found at Prang Dera, approximately 10 km to the south-southwest. I was provided with guards and guide and managed to visit the deposit (source code LKPD), which turned out to contain material of superb quality. I was told by local people that there were a handful disused mines in the area but was unable to visit any of them. The proximity of Prang Dera to the famous Khyber Pass at least opens the possibility that steatite from this source may have been accessible Harappans traveling to and from Shortughaï, that is, if it was one of the routes they took.

Also in the Khyber Agency, talc in dolomite occurs on the western side of the Peshawar Valley, 6 km north of the Khyber Pass entrance at Jamrud (Abbas *et al.* 1967). I visited this deposit in November of 2000 and found the steatite there to be foliated and filled with inclusions. Higher-grade stone could have been present in the past (the deposit has reportedly been worked for 50-plus years). However, the material described in a report by Abbas and others (1967) thirty years ago was also of mediocre quality.

*- Peshawar District*

In the southeast part of the Peshawar District, soapstone in metamorphosed Attock slate is found at Kund and nearby Kath Miani (Heron and Crookshank 1954: 138-139). At the outset of this project, I considered these deposits to be potentially very important because of their location at the entrance of the Peshawar Valley near the fording point of the Indus River at Attock, as well as because of their relative proximity (≈ 60 km) to the Early

Harappan sites of Sarai Khola and Hathial. However, after having visited the Kund deposit and analyzing samples collected there (Figure 7.19), I am of the opinion that Harappans probably did not acquire any steatite from these occurrences. Below, I go into slightly greater detail in my discussion of the Kund-Kath Miani deposits in order to provide an illustration of exactly how I made judgments as to what constituted sources of "Harappan-quality" steatite. Such judgments ultimately determined which sources were selected to be compared to steatite artifacts in geologic provenience analyses.

To begin with (and most importantly), Kund soapstone is heavily foliated and easily fractures into platy pieces. Harappan craftspeople would have found it to be completely unsuitable for sawing or carving. Secondly, XRD analysis (Figure 7.19 *bottom right*) indicates that the Kund material is a chlorite-talc soapstone rock with quartz impurities. No chlorite phases have ever been detected in any of the raw steatite artifacts analyzed from Harappa. These observations are backed up by a previous study of Kund soapstone by Qaiser and others (1980) who also described eight slately and friable samples, most of which had major chlorite phases and significant other impurities. Although I did not sample the nearby occurrence at Kath Miani, Heron and Crookshank's description (1954: 139) of the material there – "impure soapstone mixed with shale debris," suggests it is of the same low quality.

There is, of course, always the possibility that, in former times, a higher-quality steatite occurred at the Kund / Kath Miani deposits, but that it has since been mined out. However, given the foliated nature of the original parent-rock (Attock Precambrian slates) I doubt that is true. Vidale and Bianchetti analyzed (1997: 949) a block of "whitish steatite" that was purchased in Khairpur, Sindh but which was said to have been mined near Attock. XRD of that sample showed it to be pure talc. I highly doubt that that it could have originated in the Kund / Kath Miani deposits. It probably came from one of the other sources in the general region like those in the Hazara District or the Mohmand Agency, both of which are around 75 km away from the Attock area.

*- Mohmand Agency*

In the Mohmand Agency, steatite occurs in the western part of the Sakhakot-Qila ophiolite (Rafiq 1984: 58) located on the northwest margin of the Peshawar Valley. Good quality material was located during an August 2001 collection trip to that formation with Dr. Irshad Ahmed of the Center of Excellence in Geology, University of Peshawar. Samples were taken around Kot Mazarai (source codes Kot and Kot (MP)), which happens to be in the same vicinity as an important source of vesuvianite-grossular (Chapter 9).

*- Chitral District*

In the Shi Shi Valley – an off-shoot of the Chitral Valley in the southern Chitral District – good quality steatite occurs in the Drosh ophiolite near the village of Tar (Calkins 1981: 9). Samples were collected from this location (source code CHT) in July of 2000. Although this source is admittedly far removed from the Indus Valley, it should be noted that one of the important routes to the lapis lazuli mines in the Badakhshan District of northern Afghanistan passes through the Chitral Valley.

*- Northern Areas*

Like Chitral, Pakistan's Northern Areas may seem as if it is too remote to have figured significantly into Harappan steatite acquisition networks. However, major routes connecting South Asia to Central Asia traverse this region and ancient petroglyphs found alongside these routes provide evidence for the long history of their use (Jettmar 1991). Steatite occurrences in the region include those in the Chalt area in the Gilgit District (Bender 1995b: 273) and several in the Shyok Valley of the Skardu District

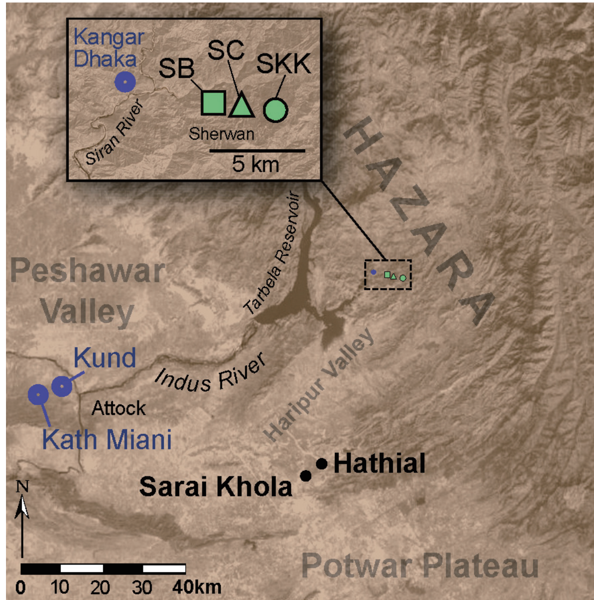


**Figure 7.20** The Shewan area, Hazara District, NWFP.

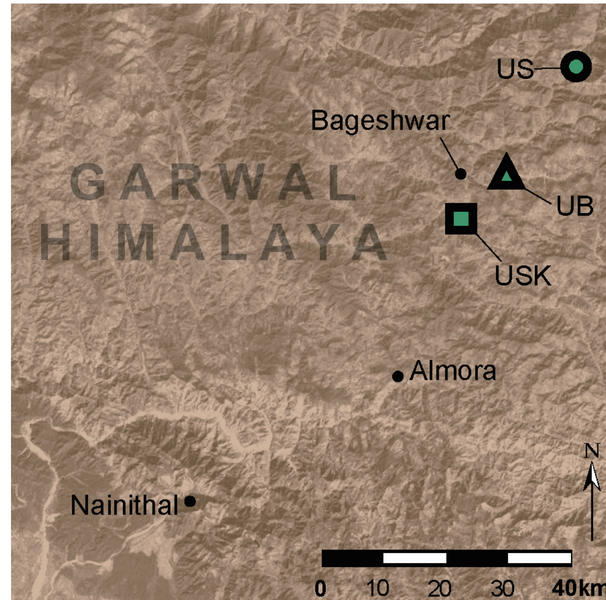


**Figure 7.21** The steatite deposit at Chelethar, Hazara District, NWFP.

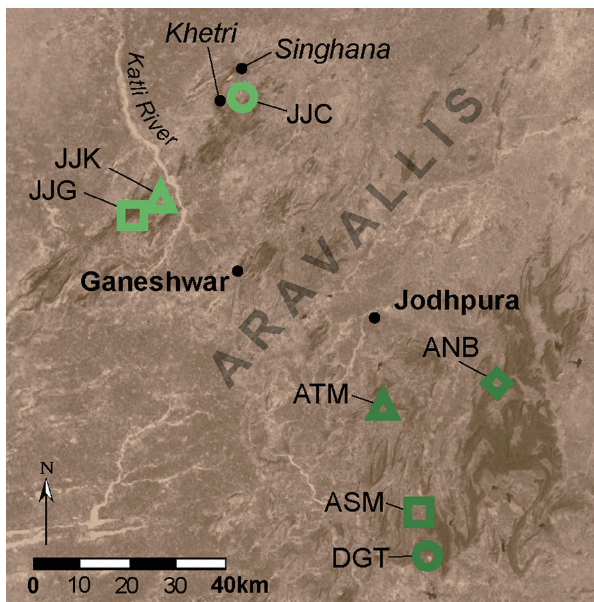
**Figure 7.22** Details of regions where multiple steatite deposits were sampled.



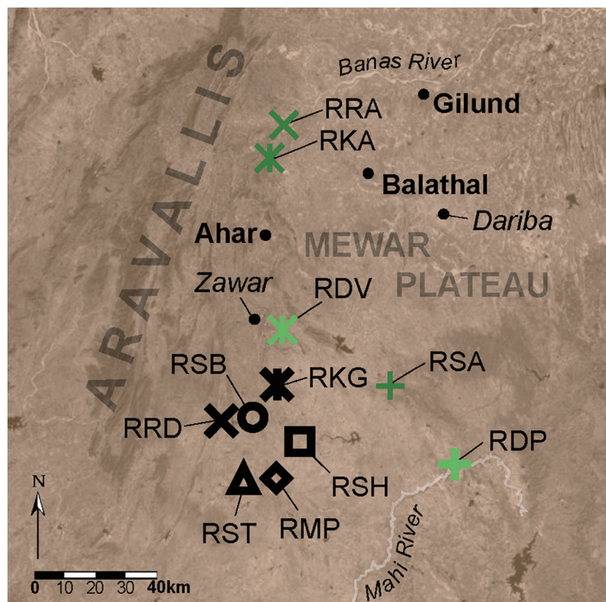

**A**. Sampled steatite deposits of the Hazara District, NWFP, Pakistan.




**B**. Sampled steatite deposits of the Bageshwar District, Uttaranchal, India.




**C**. Sampled steatite deposits of the Jhunjhunu, Alwar and Dausa districts, northern Rajasthan, India.




**D**. Sampled steatite deposits of the Rajsamand, Udaipur and Dungapur districts, southern Rajasthan, India.

(Kazmi and Jan 1997: 481). Superb quality steatite from the Ishkoman region near the Afghanistan border can be seen in the Geological Survey of Pakistan's Museum collection in Quetta (Case 22).

*- Swat District*

A major tectonic boundary (the Main Mantle Thrust) passes along the length of the lower Swat Valley and zones of talcose rock are found all along it (Di Florio *et al.* 1993). I examined several locations in the valley itself but failed identify any occurrence of artifact quality steatite (admittedly though, my sampling excursions there were brief and spotty). Excellent steatite does occur, however, in the eastern part of the Swat District (outside of the Swat Valley proper) within the dolomitic sequences of the Derai

and Juragh areas (Ghani *et al*. 1994; Kazmi and Jan 1997: 312, 482). One deposit (source code BESH) in this zone, which I sampled with Dr. Mark Kenoyer in May of 2000, lies just 7 km from the Indus River near the town of Besham. The steatite at this location is of excellent quality.

*- Hazara District*

The most extensive steatite deposits in Pakistan are found in the Sherwan area (Figures 7.20, 7.21 and 7.22 A) of the Hazara District, NWFP (Shah 1977: 199). The deposits occur in the dolomite sequence of the Precambrian Abbottabad Formation and extend intermittently across a zone over 16 km long and 2 km wide (Ali *et al*. 1964: 29-34; Bender 1995b: 273; Calkins *et al* 1973). As the chapter continues, I frequently refer to these occurrences as the "Sherwan zone." I visited this zone with Dr. Syed Baqri of the Pakistan Museum of Natural History in August of 2000. We conducted sampling around three locations where some of the largest deposits occurred – Bandi (source code SB), Chelethar (SC) and Khanda Khu (SKK). Excellent quality material was available at each of these locations and numerous old pits and shafts were observed, especially around Khanda Khu. There are several important occurrences in the Sherwan zone that time did not permit us to sample. A deposit at Khangar Dhaka, which separated from the main body of occurrences by the Siran River, is said to contain the highest quality material in the area (Ali *et al*. 1964: 34).

The Sherwan deposits lie 50 to 60 km north-northwest of the Kot Dijian sites of Hathial and Sarai Khola (Figure 7.22 A). People dwelling at those settlements could have easily reached these sources by traveling up the Haripur Valley to the Siran River Valley (now partially flooded by the Tarbela Reservoir), which transects the zone along which they occur.

***Steatite occurrences in the Himalayas***

*- Jammu and Kashmir*

The steatite occurrences of Jammu and Kashmir take on a special significance in light of the clear evidence at the site of Burzahom for some form of interaction between the ancient peoples of the Kashmir Valley and those of the Indus Valley during the Early Harappan period (Saar 1992). There are a numerous routes into and out of the Vale of Kashmir that would have passed near to many of the deposits discussed in this sub-section.

Ali (1959: 10) reported an occurrence of soapstone at Chilhana Da Dana in the Muzaffarabad District but provided no details regarding it. In the Kotli District, soapstone deposits in dolomitic rock (at Palana and Nawal) are said to be "generally impure" (Ahmad 1981: 25). In the Zanskar area of Ladakh, "pockets of talc" are reported in ultramafic rock (Varadan 1977: 63). The descriptions of steatite at Nagri and, especially, at Chinchora in the Doda District give the impression that good quality material might be found at those locations (Indian Bureau of Mines 1992: 109).

In terms of this study, perhaps the most important steatite deposits in the entire Jammu and Kashmir region are those occurring in the southern part of the Great Limestone Formation in the Udhampur District (Chatterjee 1964: 436). The Early Harappan and Harappan Period foothills settlement of Manda (Joshi and Bala 1982) lies just 25 km to the southwest. Later, in Chapter 12, I present evidence showing that much of the raw lead ore found at Harappa quite possibly came from occurrences in the Great Limestone Formation. "Talc in compact form" is reported at four different locations in that formation – Kunian, Kashikaria, Nangal and Puran Daruhur (Indian Bureau of Mines 1992: 109). All are either adjacent to or in the vicinity of Vaishno Devi – the highly revered mountain-top shrine that is today one of India's major pilgrimage places. High security at the shrine and in the hills around it prevented me



**Figure 7.23** Painthal steatite deposit, Udhampur District, Jammu.



**Figure 7.24** Outcrop of grayish steatite at Painthal.

from reaching the sources. Fortunately, with the help of Ajay Kumal of the Geological Survey of India's office in Jammu, I was able to locate and sample another steatite deposit in the Great Limestone Formation at a place called Painthal (source code JAMPT), which is on a ridge-top (Figure 7.23) five kilometers due east of Vaishno Devi. The raw steatite occurring at this location (Figure 7.24) is generally gray in appearance with the occasional patches of khaki to grayish-green material. Significantly, an unfinished seal was discovered in Early Harappan/ Harappan levels (Period 1A) at Manda (Joshi and Bala 1993: 241). Although it is difficult to tell from the black and white photograph (ibid: Plate LXXIII C), the seal would appear to be carved from a dark grey steatite very much like that found at Painthal.

*- Himachal Pradesh*

Only two occurrences of steatite have been reported in all of Himachal Pradesh – one near Asrang in the Kinnaur District and another at Nahan in the Sirmaur District (Chatterjee 1964: 436; Indian Bureau of Mines 1992: 109; Geological Survey of India 1989a: 52). The Asrang deposit, although remote, was easy to locate. However, I did not end up analyzing any of the samples collected there for this provenience study because the material I found was too soft, friable and impure to be Harappan-quality steatite.

"Good quality steatite deposits are reported nearby Nahan" (Indian Bureau of Mines 1992: 109) but when I traveled to that area in June 2003 I failed to locate any sign of them or any local person around who knew of them. I visited the Geological Survey of India's office in Chandigarh and met with N.L. Sharma and his colleagues, some of whom do research around Nahan. None of them had any knowledge of steatite or, for that matter, any kind of talcose stone in the area. Gypsum deposits and mining operations are found in southeast Himachal Pradesh around Nahan, however. The gentlemen from the GSI suggested that what was reported as steatite may have actually been that mineral. So at this point, I have to consider the report of steatite in the Nahan area to be unsubstantiated.



**Figure 7.25** Sampling steatite deposits west of Bageshwar, Uttaranchal.

*- Uttaranchal*

In contrast to Himachal Pradesh, Uttaranchal (formerly part of Uttar Pradesh) is a steatite-rich state (Chatterjee 1964: 443; Dalela 1995; Indian Bureau of Mines 1992: 161-167; Valdiya 1980: 256-257). Sources in this region (Figure 7.22 B), although located in highly mountainous and often difficult to reach areas, are important because they would have been among the closest to Harappan and Late Harappan peoples living on the Gangetic Plain.

I was unable to reach an occurrence of reportedly high-grade material in ultramafic rock at Kandyal Gaon (Pandey 1967) in the central part of the Uttaranchal due to a rock-slide related road closure. However, in June of 2003 I did manage to collect samples of good-quality soapstone of dolomitic origin from three occurrences in the Bageshwar District (formerly part of the Almora District) around Bageshwar town (Bhattacharya 1980; Indian Bureau of Mines 1992: 161-164; Ray *et al*. 1977). The first were taken from Saling mine (source code US) in the Sarju Valley north of Bageshwar; the second from along a five kilometer zone of talc mineralization (Figure 7.25) that transects two valleys that extend to the west of the town (UB); and the third from an abandoned steatite mine to the south of the town called Shisha Khani (USK), which happens to be nearby a lead mine (of the same name) that I will be examining in Chapter 12.

Additional steatite occurrences can be found to the north of the Bageshwar District at high elevations in the Chamoli District (Rao and Pati 1981) and to the west in the Pithoragarh District near the border with Nepal (Bhattacharya *et al*. 1982). However, I decided to end sampling in the Bageshwar area for reasons of time and because I felt it (arguably) constituted the northeastern margin of the Greater Indus region.

***Steatite occurrences in Rajasthan***

Sir Edwin Pascoe (1931: 679) singled out the Indian state of Rajasthan (or "Rajputana" as it was called prior to 1947) as the most likely source area for the raw material used to make the steatite artifacts excavated at the site of Mohenjo-daro. Most of the other researchers (cited previously) who have weighed in on the subject of steatite acquisition by Indus Civilization peoples have either concurred or at least ranked the region high on the list of potential source areas. There is, of course, a very good reason for this. With all due respect to Ashiq Hussain and to the johris of Shah Noorani, if there is truly a "land of zahr muhra" it is Rajasthan. Steatite occurs in nine well-defined belts that run through 16 of that state's districts (Gahlot and Shukla 2000: 113) and, as of about a decade ago, there were 335 official mining leases there (Rajasthan Mineral Bulletin 1997b: 17). There are likely as many or more unofficially worked deposits and innumerable occurrences that are today considered too small to be commercially viable (*personal observations*).

Even though I devoted a large portion my available resources to the analysis of samples from this very rich potential source area (over one third of all the geologic samples analyzed came from deposits in Rajasthan), it simply would have been impossible to adequately assess steatite occurrences in all parts of the Rajasthan. So instead, I focused on obtaining samples from deposits in steatite belts situated in the northern and southern parts of the Aravalli Range, as these are the areas adjacent to regions where there were Harappan settlements (i.e, Gujarat in the south and Haryana in the north) as well as where there were well-known Chalcolithic cultures that Harappans may have interacted with (the Ahar-Banas complex of southern Rajasthan and the Ganeshwar-Jodhpura complex of northern Rajasthan). Multiple sampling trips were made between 2001 and 2003. For many of these journeys I was joined by Dr. Kishore Raghubans, who was at the time conducting his dissertation research on the Ganeshwar-Jodhpura complex of northern Rajasthan. On Figure 7.2, the six districts of

Rajasthan where sampling took place are marked with labeled ellipses. The ten remaining districts where steatite also occurs in the state (but which remain to be sampled) are labeled in blue.

*- Northern Rajasthan*

During the third millennium BC, peoples of the non-urbanized Chalcolithic Ganeshwar-Jodhpura society inhabited areas in and around the northern part of the Aravalli Mountain Range (Agrawala and Kumar 1982; Rizvi 2007). Harappan acquisition of steatite from occurrences in this region (Figure 7.22 C) would have necessitated interaction with them. The deposits discussed in this sub-section lie between 140 and 240 km south of the Indus Civilization city of Rakhigarhi in Haryana.

Jhunjhunu District

The Indian Bureau of Mines lists (1992: 142) only three deposits of steatite in the Jhunjhunu District – at Chirani-ki-Dhani (JJC), Gurda (JJG) and Kho (JJK), all of which occur in "dolomite country rocks" (ibid.). All three deposits were visited and, even though it was not abundant at any of them, samples of Harappan-quality material were acquired. Importantly, these deposits lie within what constitutes the northern part of the Khetri Copper Belt (Raghunandan 1975). If the Khetri belt was one of the major copper sources for Indus Civilization peoples as many researchers have proposed (see Chapter 12 for a full discussion), then steatite may have been a resource that was acquired from this area at the same time. Note that the occurrence at Chirani-ki-Dhani is located less than 10 km from both Khetri itself and the enormous copper smelting slag heaps at Singhana.

Alwar and Dausa districts

In the northeastern part of the Aravalli Range, steatite is reported at a few dozen places in the dolomitic limestone of the Riaolo Formation (Gahlot and Shukla 2000; Indian Bureau of Mines 1992; Rajasthan Mineral Bulletin 1997b). In the Alwar District, samples for this study were taken at Nangalhari-Bairaswas (ANB) (figures 7.26 and 7.27), Teori (ATM) and Samra (ASM). Like the deposits of the Jhunjhunu District, Harappan-quality stone was present but not abundant. Slightly farther to the south in the Dausa District (formerly part of the Jaipur District), the situation was very different, however. The huge open pit mine at Degota (DGT) is largest in Rajasthan and produces some of the highest grade soapstone in India. In fact, much of the stone that is being taken out of the mine is too good. That is, it was massive and compact (and would have carved beautifully) and pure white. None of the archaeological examples of raw steatite that I have ever seen have been pure white. Searches of areas along the margins of the mine (closer to the ground surface and country-rock) yielded colorful steatite samples that were much more Harappan-like in appearance.

*- Southern Rajasthan*

In southern Rajasthan (Figure 7.22 D), settlements belonging to the Chalcolithic Ahar-Banas culture complex (Shinde *et al*. 2005) like Gilund, Balathal and Ahar are found on the eastern flank of the Aravalli Range and Marwar Plateau area. Although no less than 250 km separated these non-urban agro-pastoralists from the Harappans of Gujarat, the rich rock and mineral resources of the region may have brought the two societies into contact.

The lithostratigraphy of southern Rajasthan consists mostly of Precambrian rocks that have been repeatedly "folded, faulted, metamorphosed and migmatized" over the course of last 700 million to two-and-a-half billion years (Prasad *et al*. 1997: 16). Throughout the complex geologic mélange of the region there are hundreds steatite deposits. They occur in zones or "belts" within ultrabasic (ultramafic) igneous rocks (in this case of the non-ophiolitic variety) and in sedimentary magnesium carbonate rocks (Gahlot and Shukla 2000: 111-112). Because



**Figure 7.26** Steatite deposit at Nangalhari-Bairaswas, Alwar District, Rajasthan.



**Figure 7.27** Detail of the steatite body at Nangalhari-Bairaswas.



**Figure 7.28** The extensive open-pit steatite mine at Deola, Dungarpur District, Rajasthan.



**Figure 7.29** The steatite outcrop at Shiv Bola, Udaipur District, Rajasthan.

these belts often cross district boundaries, I discuss the deposits that were sampled in this region according to their parent-rock types rather than their geographic location. Sources of dolomitic origin are marked with green symbols on Figure 7.22 D while black symbols mark those of ultramafic origin.

One note before proceeding. Throughout this entire section I have taken great pain to discuss not only the deposits of Harappan quality stone that I sampled but also all other occurrences (of any nature or quality) that I visited or read about in the geologic literature. This was necessary in order to

provide a rough indication of how representative the sources that I sampled were of the deposits present in each region (or at least those documented in each region). In southern Rajasthan the situation is different, however. There were a dozen or so mines and outcrops in the region that I visited but sampled only sparingly (or not at all) because the material at them was subpar. There is no need to mention them below because there are unquestionably hundreds more like them. Nor is it necessary to try to list the plethora of excellent quality steatite deposits that I was unable to visit. It is enough to recognize that the materials collected, although carefully selected to be geographically and geologically representative, constitute an extremely small sample of steatite in this region.

Dolomitic occurrences sampled

The various dolomitic formations of southern Rajasthan all belong to the Early Proterozoic (ca. 2500 – 2000 m.y.a.) *Aravalli Supergroup* of rocks (Gupta *et al*. 1997).

In the Rajsamand District, a belt of steatite extending around 29 km occurs in the dolomitic marble of the Haldighathi Formation (Gahlot and Shukla 2000: 111-112; Gupta *et al*. 1997: *geologic map*). Samples were collected at two mines around five kilometers apart in the center of this zone – Karoli (RKA) and Rabcha (RRA). In the central Udaipur District, steatite in Kathalia dolomite was sampled at Dev Pura (RDV) mine. This deposit lies just 12 km southeast of the famous lead-zinc mines at Zawar (Freestone *et al*. 1985; Craddock *et al.* 1989). In the southeastern part of the Udaipur district, a belt of steatite in Jagpura dolomitic begins near Salumbar mine (RSA) and terminates 40 km to the southeast at the massive Deola (RDP) open-pit mine (Figure 7.28) in the Dungarpur District (Department of Mines and Geology 1992: 13; Gupta *et al*. 1997: *geologic map*). Samples for this study were collected from each of those locations.

Ultramafic occurrences sampled

Steatite deposits of ultramafic origin in southern Rajasthan are hosted within rocks of the Rakhabdev Ultramafic Suite, which occurs in three belts (Gupta *et al*. 1997: 158-159). Geologic samples for this study were taken in the southernmost and largest belt (it actually diverges into two sub-belts) that extends from the Udaipur District into the Dungarpur District. From north to south the six mines and/or outcrops sampled were: Kali Ghadi mine (RKG), Shiv Bola mine (RSB) (Figure 7.29)and the nearby (1.5 km) outcrop at Rishab-der (RRD), Khadi Ghati mine (RSH), Shala Shah Thana mine (RST) and Manpur mine (RMP).

***Steatite occurrences in Gujarat***

The southern fringes of the Aravalli Range extend across the Rajasthan border into the northeastern part of Gujarat. Geologically, the steatite-bearing formations in that trans-border area are continuations of those to the north. The steatite deposits found in them would have been the absolute nearest sources of that stone for the Harappans of Gujarat – a fact already noted by S.R. Rao (1985: 583) in his discussion of steatite artifacts at Lothal.

Steatite samples were collected around the Dev Mori (Devni Mori) area (at Bhiloda and nearby Kundol – DMB & DMK) in the Sabarkantha District (Indian Bureau of Mines 1992: 108; Middlemiss 1912) (Figure 7.30). These deposits and six additional ones found within 10 to 35 km of Dev Mori (see Chatteerjee 1964: 436 for deposit names) are part an outlying sub-belt of the Rakhabdev Ultramafic Suite, which was discussed in the preceding section.

Around 125 km farther south, another cluster of steatite deposits is found in the Vadodara and Panchmahal districts (Geological Survey of India 2001a: 76). All occur in the dolomitic limestone formation of the Precambrian Champaner Group (Dwivedi 1984). Samples representing this cluster were taken at Gandhra (GPM) in the Panchmahal District.



**Figure 7.30** The Dev Mori/Kundol steatite mine, Sabarkantha District, Gujarat.

***A brief note on steatite occurrences in other regions***

Two other regions should be quickly noted in closing. Because of the existence of Shortughaï, the steatite deposits of Afghanistan, especially those in its eastern provinces (identified in ESCAP 1995; Orris and Bliss 2002; and Peters *et al*. 2007), must be considered potential sources. Also, the clear evidence of Harappan interaction with the Oman region (Cleuziou 1992) opens the possibility that steatite from the extensive Semail ophiolite of the eastern Arabian Peninsula may have made its way, perhaps together with copper from deposits in that formation, to consumers in the Indus Valley. Using INAA and XRD, I recently analyzed a set of unfired steatite beads and bead manufacturing debris from the early 3rd millennium BC coastal site of HD-6 in the Ra's al-Hadd area of Oman (Cleuziou and Tosi 2000). Although those data have not yet been fully integrated into the present study, they do provide an important new perspective on the results and so I will referring to them in the discussion section of this chapter.

## A GEOLOGIC PROVENIENCE STUDY OF STEATITE ARTIFACTS FROM HARAPPA AND SEVEN OTHER SITES

A set of unfired steatite artifacts from Harappa and eight other archaeological sites was presented in the first section of this chapter. The various steatite occurrences of the Greater Indus region from which those artifacts potentially may have been acquired were discussed in the second. In this section, I provide

the details and results of a geologic provenience study in which INAA-derived data was used to compare the archaeological set to geologic samples collected from over three dozen of those potential sources. Before doing so, however, I review various geologic provenience studies of steatite artifacts that have been conducted in the past. In terms of the present undertaking, those studies provided both models to follow and examples of what to avoid.

### Past geologic provenience studies of steatite artifacts

The use of quantitative methods in attempts to differentiate steatite deposits and/or assign geologic proveniences to steatite artifacts go back more than 60 years to Bullen and Howell's spectrographic analysis (1943) soapstone sources in New England. Although that initial study provided inconclusive results, more research later followed with varying degrees of success. Kohl and others (1979) used X-ray diffraction (XRD) analysis to examine 375 "softstone" vessels (most were actually chlorite but some were steatite) from sites across southwest Asia and Arabia. Although their results suggested that multiple sources were probably represented among the artifacts studied, the effectiveness of using ratios generated from X-ray peak intensities for provenience resolution proved to be limited (ibid.: 147). Turnbaugh and others (1984) employed macroscopic observations, petrography and major element profiling using atomic absorption spectrometry in a study of six southern New England soapstone quarries. Although they documented significant inter-quarry compositional variation, it was unclear if this combination of techniques could be used to confidently assign provenience to artifactual materials (ibid.: 137). Recently, Magee and others (2005) conducted a promising pilot study of 15 "softstone" (both chlorite and steatite) vessel fragments from two Iron-Age sites in southeastern Arabia using ICP-MS/OES (optical emissions spectrometry). Focusing on measured concentrations of transition metals, their results indicated that stone from multiple distinct sources was likely represented among the artifacts. This method could eventually be an effective tool for provenience determination when samples from geologic sources are included in a dataset.

The most successful geologic provenience studies of steatite artifacts to date have involved instrumental neutron activation analysis (INAA). The use of this method was pioneered by Ralph O. Allen and others at the University of Virginia who, after concluding that the relative concentrations of rare earth elements (REEs) remained more or less constant throughout steatite occurrences, characterized numerous quarries and soapstone artifacts in the eastern United States and Canada (Allen *et al*. 1975; Allen and Pennell 1978; Luckenbach *et al* 1975; Rogers *et al*. 1983). Measured REE concentrations from quarries were normalized by dividing them by REE in concentrations chondritic meteorites. An REE distributional curve profile or "fingerprint" for each quarry was generated against which chondrite-normalized REE profiles of steatite artifacts could be compared and matched. Although this seemed to work very well for Allen and his associates, Moffat and Buttler (1986) called the whole approach into question after finding that REE concentrations were too low and too variable in Shetland Islands steatite sources to be of use in provenience studies of artifacts from that region. To be fair, the extended count times employed by Allen and others (Pennell 1978 cited by Truncer 1998: 24) generated data that was much more precise than that produced by Moffat and Buttler's comparatively short measurements. However, some valid points were made regarding the need for more rigorous sampling to assess intra-source variability as well as about the usefulness of REE-profiles as quarry "fingerprints." Truncer and others (1998) took up these issues in a study at the University of Missouri Research Reactor (MURR) that partially involved the re-sampling and analysis of a number steatite quarries in eastern North

America previously characterized by Allen's group. They found INAA to still be an effective technique for differentiating individual sources and assigning geologic provenience, at least on a regional level, to soapstone artifacts. Importantly, they discovered that transition metals, rather than REEs, contributed most to steatite source discrimination and that canonical discriminant analysis (CDA) was a more appropriate method of data evaluation than REE "fingerprints."

The present study is largely modeled after Truncer and other's successful 1998 research project. It employs INAA (although irradiation and count times at the UWNR differ from those used at the MURR), focuses heavily on transition metals and relies mainly on CDA for source discrimination and provenience assignment. It differs somewhat from that and most of the other studies discussed above in its definition of what constitutes a steatite "source" and the expectations of provenience resolution stemming from it. Here a "source" area is considered to be a distinct *geologic formation* in which bodies of steatite occur, rather than an individual outcrop or quarry. For Harappa, which lays no less than 325 km from any steatite source, this level of geographic resolution is more than sufficient.

## Details and results of the present study

One hundred forty unfired steatite artifacts from Harappa, thirty-seven such artifacts from the seven additional sites and 442 geologic samples collected from 37 deposits of Harappan-quality steatite around the Greater Indus region were analyzed using INAA. Sample preparation and irradiation followed those procedures outlined in Chapter 3. For the geologic samples, the measured concentrations for 11 elements (Al, Co, Cr, Eu, Fe, La, Mn, Na, Sc, V and Zn) can be found in Appendix 7.3. For the archaeological samples from Harappa those data are listed in Appendix 7.4; for Mohenjo-daro in Appendix 7.5; for Mehrgarh and Nausharo they are in Appendix 7.6; and for all remaining archaeological samples (from Gola Dhoro, Nagwada, Loralai, Mitathal and Tepe Hissar) they are in Appendix 7.7. INAA-derived data were evaluated using CDA and cluster analysis (CA), again following procedures discussed in Chapter 2. Appendix 7.8 lists the standardized (canonical) discriminant function coefficients for all scatterplots (below) generated using CDA.

### *Initial CDA and CA comparisons of all steatite artifacts to the geologic sources*

Examination of the INAA results begins with a comparison of the geologic sources only. On Figure 7.31, the 442 geologic samples are plotted using the first and second discriminant functions generated from CDA of the 37 deposits. The symbols representing steatite samples from dolomitic parent-rock are those in shades of green (some have black or white elements) while the ones representing samples from ultramafic sources are in black and/or black and white. The map of the Greater Indus region (Figure 7.2) at the beginning of this chapter and the detail maps from the preceding section (figures 7.10, 7.15 and 7.22 A to D) serve as the symbol key for the geologic samples.

It is clear from the two distinct clusters of datapoints on Figure 7.31 that steatite deposits of dolomitic and ultramafic origin are geochemically distinct from one another. This is because the ultramafic steatite samples have a higher average concentration of certain transition metals (in particular Co, Cr, Fe, Mn and Sc) as compared to the dolomitic samples, which have higher concentrations of the two REEs Eu and La (Figure 7.33).

A minor amount of overlap between the two large clusters of deposits representing the two different parent-rock types is, however, evident on the plot. Most of it comes from two deposits – Urgasai Nasir (ZUN) and Takhahen (ZTAK), both of which are in the Muslimbagh ophiolite of northern Balochistan. At certain places, the ultramafic rock of that formation comes into contact with Mesozoic

limestones and shales (Ahmad 1974: 4; Ahmad and Abbas 1979: 245). Although more detailed field studies are needed to confirm this, ZUN and ZTAK are *perhaps* deposits formed where hydrothermal alteration has occurred at the point of contact between the two types of parent-rock. The result might then be steatite bodies having concentrations of certain metallic elements that are higher than usual for dolomitic occurrences but somewhat lower than is typical of ultramafic ones.

A second area of overlap is associated with the Rabcha deposit (RRA) of southern Rajasthan. Three samples from that source had uncommonly high Co and Cr concentrations for a dolomitic deposit.

In spite of areas of overlap, good separation overall between the groups of samples comprising the full geologic set was achieved. When the leave-one-out cross-validation function was applied, exactly 69% of grouped geologic cases were classified correctly.

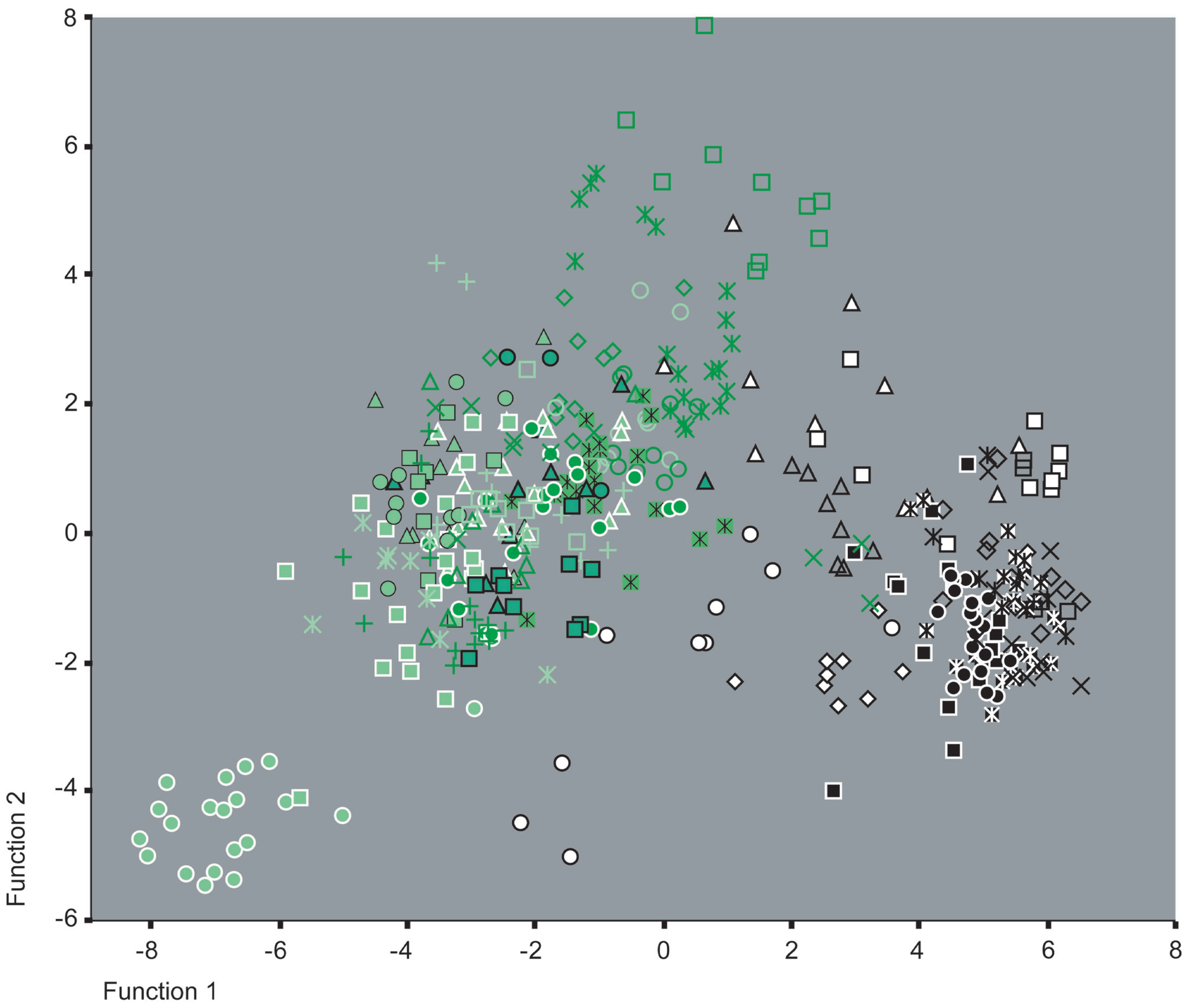
When the set of 179 artifacts are plotted as ungrouped cases in relation to the geologic samples (Figure 7.32), one thing becomes immediately clear. That is, the vast majority of the unfired steatite artifacts analyzed are composed of raw material derived from deposits of dolomitic origin. Only a handful (8 of 179) of the artifacts in the archaeological set plot in or near the cluster created by samples from ultramafic deposits. The first predicted group memberships (PGMs) for artifacts from Harappa made in this initial CDA can be found in Appendix 7.1 in the column labeled "full set" (meaning they were made in a comparison to the full geologic set). The two to five letter source codes listed correspond to those given in the text as well as those listed in column four of Appendix 7.2.

For the second round of CDA, the geologic samples were divided into two sub-sets according to their parent-rock type (ultramafic or dolomitic) and then those artifacts that had been predicted to belong to deposits of each type in the first round of analysis were compared to them as ungrouped cases. Slightly better separation than before was achieved for both sub-sets. For deposits of ultramafic origin (Figure 7.34), 71.2% of cross-validated grouped geologic cases were classified correctly while 71.3% for dolomitic sources (Figure 7.35)were classified correctly. The first and second PGMs for artifacts from Harappa made in these second-round analyses are listed in Appendix 7.1 under the column heading "parent-rock." Those results are examined in detail in the section that follows this one. The PGMs for steatite artifacts from the eight other prehistoric sites are discussed in the section after that.

Cluster analyses (CA) were also performed on 177 steatite artifacts[1)] and the full set of geologic samples. Multiple clustering strategies were employed and the dendrograms produced in each one (not shown) were, on the whole, very similar to one another. Figure 7.36 is a dendrogram (divided into three parts in order to fit it on a single page) made using the *complete linkage* (also called *furthest neighbor*) method and a squared Euclidian distance measurement. In Appendix 7.9, it is reproduced on 15 pages (sections A through O) and the artifact/sample number for each case in it is provided. Preceding the number for most of the artifacts from Harappa is one of four short codes in parentheses – "(C1)" through "(C4)." These codes, which denote a numbered cluster in which the artifact is a member, are used in a later CA of 140 archaeological samples from Harappa (Figure 7.40).

Just as in the original CDA of the full geologic set (Figure 7.31), samples from ultramafic sources form a group/cluster that, for the most part, is highly distinct from those formed by samples collected from dolomitic deposits. Four "main" clusters – one entirely composed of ultramafic samples and three entirely or mainly composed of dolomitic ones, were

1) Two artifacts - the seal boss (H90/3208-68) from Harappa and the seal fragment from Mitathal - were added to this study at the last minute and, therefore, it was not possible to revise the cluster analyses presented in this chapter to include them.




# Figure 7.31

All 442 geologic steatite samples from the 37 locations are compared. Each location is evaluated as an individual group

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, Sc, V, Zn

Symbols representing samples from **dolomitic** parent-rock are those in shades of green (some of them have black or white elements). Symbols that represent steatite from **ultramafic** sources are in black and/or white only.

For **key** to source symbols see figures 7.2, 7.10, 7.15 and 7.22 A to D

# Figure 7.32

All 179 steatite **artifacts** analyzed for this study are plotted as ungrouped cases in relation to the 442 geologic samples.

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, V, Zn

**Artifact key**
- Harappa
- Mohenjo-daro
- Mitathal
- Mehrgarh
- Nausharo
- Loralai fragment
- Loralai beads
- Gola Dhoro
- Nagwada
- Tepe Hissar

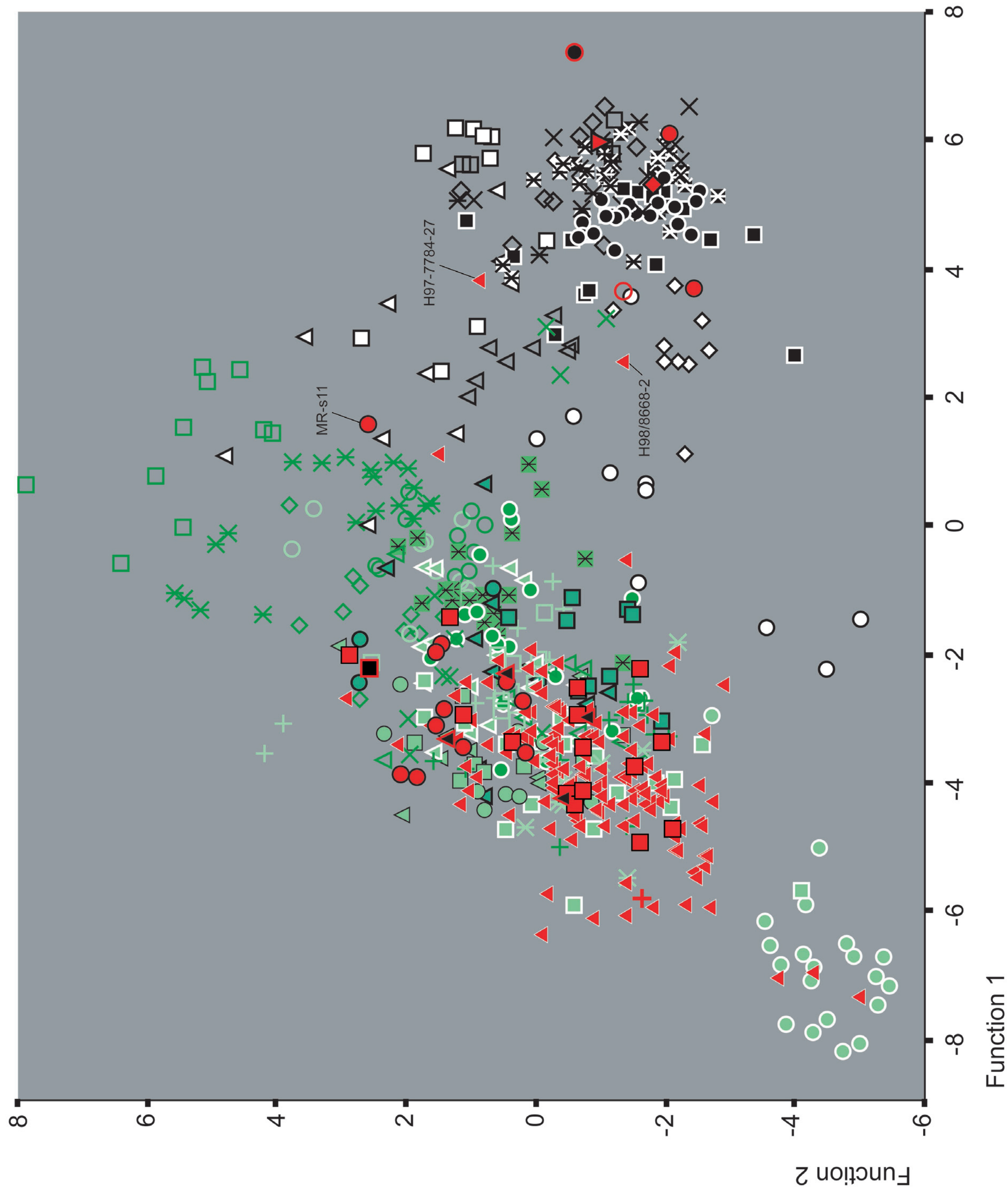
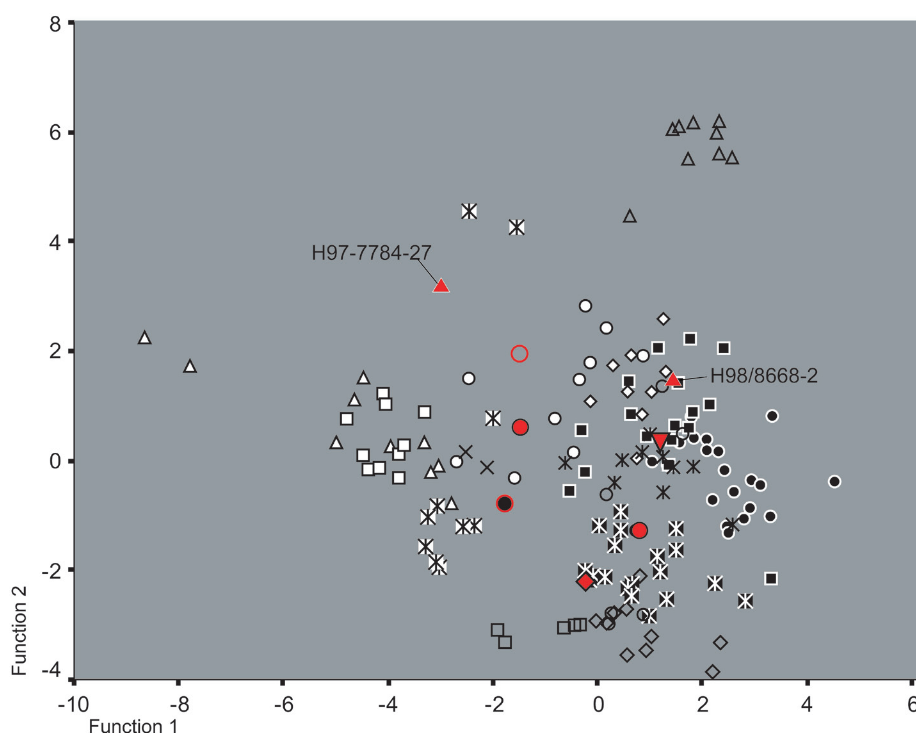


**Figure 7.33** Average elemental concentrations (PPM) in dolomitic vs. ultramafic steatite sources

| element | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **dolomitic** *average* | 15170 | 9.2 | 24 | 0.26 | 14854 | 3.69 | 80 | 1065 | 2.45 | 23.7 | 78.5 |
| **ultramafic** *average* | 13156 | 69.1 | 1297 | 0.16 | 30458 | 1.53 | 286 | 538 | 4.14 | 24.4 | 56.5 |



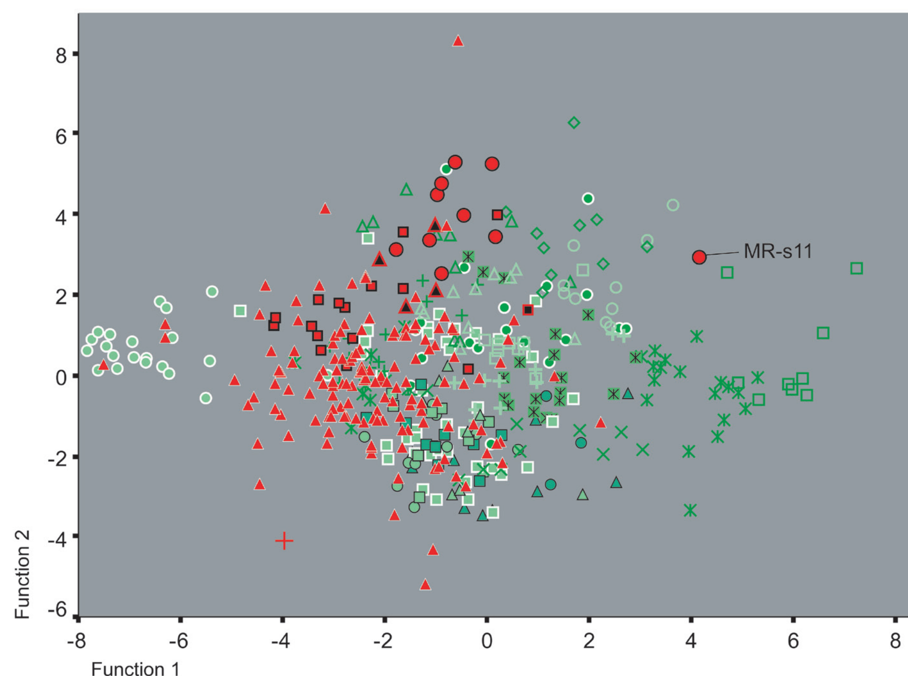

## Figure 7.34:

Select steatite **artifacts** plotted as ungrouped cases in relation to the 153 geologic samples from 14 **ultramafic** steatite deposits.

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, V, Zn

For **source key** see figures 7.2, 7.10, 7.15 and 7.22 D

**Artifact key**
- ▲ Harappa
- ● Mehrgarh
- ● Nausharo
- ○ Loralai beads
- ▼ Gola Dhoro
- ◆ Nagwada




## Figure 7.35:

Select steatite **artifacts** plotted as ungrouped cases in relation to the 289 geologic samples from 23 **dolomitic** steatite deposits.

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, V, Zn

For **source key** see figures 7.2 and 7.22 A through D

**Artifact key**
- ▲ Harappa
- ■ Mohenjo-daro
- ■ Mitathal
- ● Mehrgarh
- + Loralai fragment
- ▲ Tepe Hissar

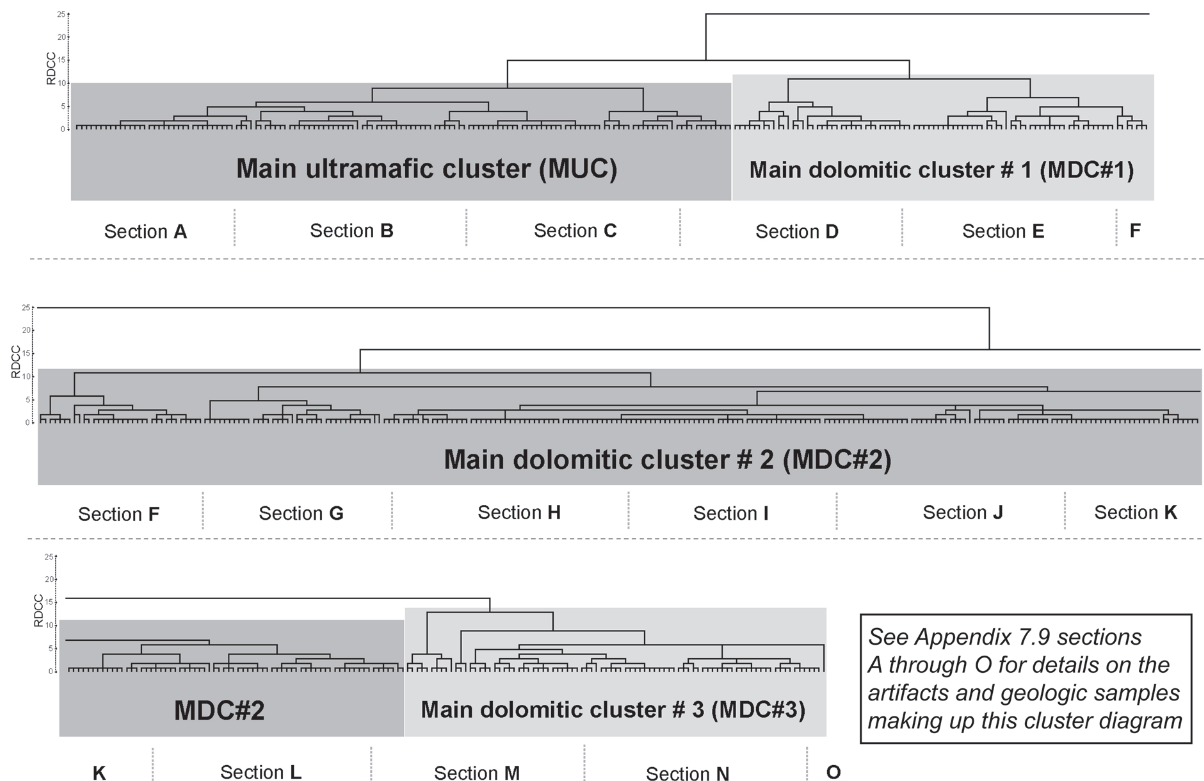



**Figure 7.36** Cluster analysis of 177 steatite artifacts and 442 geologic samples.

designated (discussed below) and are labeled on Figure 7.36. There is a modicum of overlap between the two types of geologic parent-rock and, as before, it is due mostly to samples from two deposits (ZTAK and ZUN) in the Muslimbagh ophiolite clustering among the dolomitic sources. A small number (10) of samples from other ultramafic deposits (LBW1 and RST) also appear in the dolomitic clusters. None from dolomitic sources appear within the ultramafic cluster, however. The great majority of steatite artifacts (170 of 177) cluster with samples from the various dolomitic sources, just as in the original CDA comparison of the full archaeological set to the full geologic set (Figure 7.32).

On each dendrogram there is a numbered axis that is labeled *rescaled distance cluster combine* (or RDCC). This scale is used to indicate the similarity/dissimilarity between two clusters by providing the value for the point that they meet (join or split). RDCC values are generated by rescaling the various distance measurements made in the CA from 1 (closest or most similar) to 25 (farthest or least similar). In the initial CA of the archaeological and geologic sample sets (Figure 7.36), the two most dissimilar clusters (those that split at RDCC 25) were: 1) a combined group (macrocluster) consisting of both a cluster of ultramafic samples and artifacts and a cluster of dolomitic ones and 2) another macrocluster made up mainly of dolomitic samples and artifacts. The former macrocluster splits at RDCC 15 (noted in section D of Appendix 7.9) and was subsequently divided at that point into the "Main ultramafic cluster" (MUC) and "Main dolomitic cluster #1" (MDC#1). The latter macrocluster was divided into main dolomitic clusters #2 and #3 (MDC#2 and MDC#3) based on a split that occurs at RDCC 16 (Appendix 7.9 Section J).

There are numerous other distinct clusters evident within each of the four "main" ones that have defined (Figure 7.36). However, no designations are given to them at this point because none represent complete, geologically homogenous groups. That is to say, none of the individual geologic sources in the dataset can have all of its members encompassed into a single

cluster without also having members from other geologic sources included in it. The reason for this is that many deposits in the geologic dataset are highly variable geochemically as well as compositionally similar to one another. Consequently, samples from many deposits spread widely across the dendrogram, clustering near those from different sources that are compositionally like them. Whereas there was a very minor degree of overlap between the ultramafic and dolomitic sources when they were considered as unified groups, at a level of comparison involving individual deposits the degree of overlap is much more significant. The outcome has already been seen in the results of the initial CDA of the datasets discussed above. Because of the overlap between various deposits in the geologic dataset, group discrimination is imperfect. This continues to be the case in CDAs performed in the next section. The correct classification success rate for cross-validated geologic samples will, at best, only ever approach around 80%. What it means for this study is that it is not possible to simply observe where an artifact falls on the CA dendrogram, note which geologic samples cluster with it and make a specific provenience determination based on that observation.

In spite of the overlap issue, a great deal of information, including much regarding the possible geologic proveniences of unfired steatite artifacts, can be gleaned from the dendrogram of the archaeological and full geologic sets (Figure 7.36). However, because the data depicted are very complex, effectively interpreting it requires having a full and detailed understanding of the variability of the geologic samples and of the associations that the artifacts have with them. This is gained through multiple CDAs of refined and regrouped versions of the geologic dataset along with CAs that focus on specific subsets of artifacts. These analyses are detailed in the next section, as artifacts from Harappa are first put through a series of CDA comparisons to the geologic set and then evaluated (both as a separate assemblage and in relation to the full geologic set) using CA. The results are then interpreted with reference to the three lines of inquiry outlined in Chapter 1. In the subsequent section, the artifacts from the other sites are similarly analyzed and interpreted.

***Unfired steatite artifacts from Harappa***

*- Canonical discriminant analyses*

When compared by CDA to samples from the 37 geologic deposits (Figure 7.32), the predicted group membership (PGM) for 139 of the 141 steatite artifacts from Harappa was one of the dolomitic sources. The two artifacts predicted to belong to an ultramafic deposit are labeled on figures 7.32 and 7.34. H98/8668-2 – the BMAC wig (Figure 7.5 E), was assigned to the Sakhakot-Qila deposit (KOT) of the NWFP. H97-7784-27 – a sawn fragment, was assigned to the Duddo deposit (LBW1) of southern Balochistan. These PGMs are evaluated and their implications discussed at the end of this section.

We now focus just on the 139 unfired steatite artifacts from Harappa that in the first CDA of the full geologic set (Figure 7.32) were predicted to belong to one of the dolomitic sources. Figure 7.37 is a summary table of the PGMs from that analysis and from three subsequent ones (PGMs are listed for each individual artifact in the final four columns of Appendix 7.1). Out of the 23 dolomitic deposits sampled (each of which was treated as an individual group during CDA) only 14 had any of the 139 artifacts assigned to them during the various CDAs. In the first two columns of Figure 7.37, those 14 are listed according to the region in which they are found. The third column shows the number of unfired steatite artifacts that were predicted in the initial "full set" CDA to belong to each of those deposits. The first highest PGM for 87 of the artifacts (or around 63% of the total number) was one of the three Sherwan zone deposits in the Hazara District of the NWFP. Seventeen were assigned to the Painthal, Jammu source; thirteen to the Prang Dera deposit in

the Khyber Agency and five to the Daradar deposit in the Safed Koh Range of the Kurram Agency.

In total, 124 of the 139 artifacts most closely resembled steatite from deposits in a region 330 to 445 km north of Harappa. I will frequently refer to this as the "northern" region. Of the remaining 16 artifacts, the first PGMs for eight were in northern Rajasthan, six were in southern Rajasthan and the PGM of two was the Shisha Khani deposit in Uttaranchal. This initial CDA has not only shown that residents of Harappa were almost exclusively using dolomitic steatite, but also indicated that the majority of it was likely acquired from deposits in the "northern" region, in particular those in the Sherwan zone. Only a small percentage (≈ 12%) of this variety of stone appeared to be from deposits in other regions.

Next, we examine the results of the second CDA (Figure 7.35) in which artifacts of dolomitic origin were compared only to samples from the 23 dolomitic deposits in the geologic set. The fourth column of Figure 7.37 (heading "all dolomitic sources") shows the number of the 139 examples from Harappa predicted to belong to each of the 14 deposits that were assigned artifacts. The first PGMs for this analysis were largely the same as in the initial one. Only 19 artifacts (or around 14%) were reclassified. For several of those cases, the new prediction was another deposit in the same geologic formation (such as SKK being reclassified as SC in the Sherwan zone) and for many others it was another deposit in the same general region (such as SB in the Sherwan zone changing to JAMPT in Jammu). The first highest PGM for 79 of the artifacts (57% of the total number) was one of the three Sherwan deposits and, altogether, 117 artifacts were assigned to sources occurring in the general region to the north of Harappa. The remaining 22 were predicted to belong to deposits in Uttaranchal and Rajasthan. Two additional deposits – Karoli in southern Rajasthan (RKA) and Chatikhet/Kanda in Uttaranchal (UB), were assigned an artifact each.

Several additional rounds of CDA were performed in which those deposits *not* predicted to be a source of any of the artifacts were removed from the geologic set. The refined set was then re-analyzed and re-compared to the dolomitic artifacts from Harappa. Throughout this process the artifact PGM patterns remained more or less the same. Finally there came a point when 11 deposits remained in the dolomitic sub-set, each of which was predicted to be the source of at least one artifact. Figure 7.38 is the scatterplot from that last CDA. Nearly 80% (78.8%) of cross-validated grouped cases now classified correctly. The PGM summary is in Figure 7.37 under the column heading "11 dolomitic sources." This time around 94 of the 139 artifacts (68%) were assigned to one of the Sherwan deposits. Together with those from Jammu and the FATA, a total of 129 artifacts (93%) were predicted to belong to "northern" region sources. Only ten artifacts were assigned to groups made up of samples from deposits in Rajasthan or Uttaranchal.

One final CDA involving the 139 dolomitic artifacts from Harappa was performed. For this one, all dolomitic deposits occurring within the same geologic formations were combined to create new *regional* groups. So, for instance, the three deposits sampled in the Abbottabad Formation of the Hazara District, which had previously been treated as separate groups, were combined into one new group designated "Sherwan." In this way, new regional groups were created (and named) for "Uttaranchal," "Jhunjhunu," "Alwar & Dausa" and "southern Rajasthan." Those deposits that were the only occurrence sampled in a particular formation were left unchanged and retaining their original source codes.

It was expected that some discriminatory power would be lost by combining broadly related deposits in this way. Indeed, when the leave-one-out cross-validation function was applied to the regrouped dataset the correct classification success rate fell to 66.8% – slightly lower than what it had been for the original CDA of the full geologic set. However, combining deposits allowed significantly

**Figure 7.37** Predicted group membership (PGM) summary table for four CDAs of the138 unfired steatite artifacts from Harappa belonging to dolomitic sources.

| **region** | ***deposit*** | **Full geologic set 1st PGM** | **All dolomitic sources 1st PGM** | **2nd PGM summary for All dolomitic sources analysis** | **11 dolomitic sources 1st PGM** | **Regional dolomitic 1st PGM** |
|---|---|---|---|---|---|---|
| **FATA** | Kurram-Daradar (PD) | 6 | 7 | SBx4, SKK x2 USK | 7 | PD<br>15 |
| | Khyber-Prang Dera (LKPD) | 13 | 12 | ATM, BESH x3, RDP x2, SB, SC x4, SKK | 14 | LKPD<br>15 |
| **NWFP** | Sherwan deposits<br>Bandi (SB) | 57 | 47 | ATM, JKK x2, PD x7, RSA x2, LKPD x7, SC x2, SKK x26 | 40 | Sherwan (SB,SC, SKK)<br>83 |
| | Chelethar (SC) | 13 | 14 | JJG, LKPD, RDP, SB x3,SKK x8 | 16 | |
| | Khanda Khu (SKK) | 17 | 18 | PD, SB x10, SC x6, UB | 38 | |
| **Jammu** | Painthal (JAMPT) | 17 | 19 | BESH, LKPD, RSA x7, SB x5, SKK x2, USK x3 | 14 | JAMPT<br>16 |
| **Uttaranchal** | Bageshwar deposits<br>Chatikhet to Kanda (UB) | 0 | 1 | SC | 0 | Uttaranchal (UB,US, USK)<br>2 |
| | Shishi Khani (USK) | 2 | 2 | SKK x2 | 2 | |
| **Northern Rajasthan** | Alwar deposits<br>Nangalhari-Bairaswas (ANB) | 1 | 1 | ATM | 2 | Alwar &Dausa (ANB, ATM ASM, DGT)<br>0 |
| | Teori (ATM) | 4 | 4 | JJK, RSA, SB x2 | 2 | |
| | Jhunjhunu-Kho (JKK) | 3 | 5 | ATM x2, RDP, SB x2 | 0 | Jhunjhunu (JJC, JJG, JJK)<br>5 |
| **Southern Rajasthan** | Dungarpur-Deola (RDP) | 1 | 1 | SC | 2 | Southern Rajasthan (RRA, RKA, RDV, RSA, RDP)<br>3 |
| | Udaipur-Salumbar (RSA) | 5 | 7 | LKPD, SB x3, SKK x2, USK | 2 | |
| | Rajsamand-Karoli (RKA) | 0 | 1 | PD | 0 | |

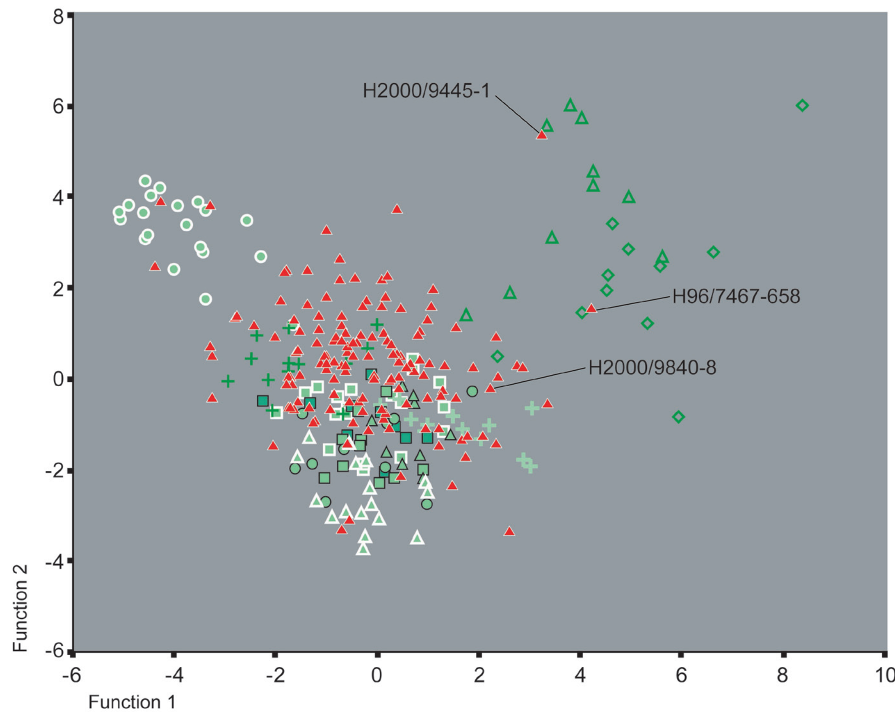



**Figure 7.38:**

Harappan steatite **artifacts** plotted as ungrouped cases in relation to the geologic samples from 11 **dolomitic** steatite deposits.

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, V, Zn

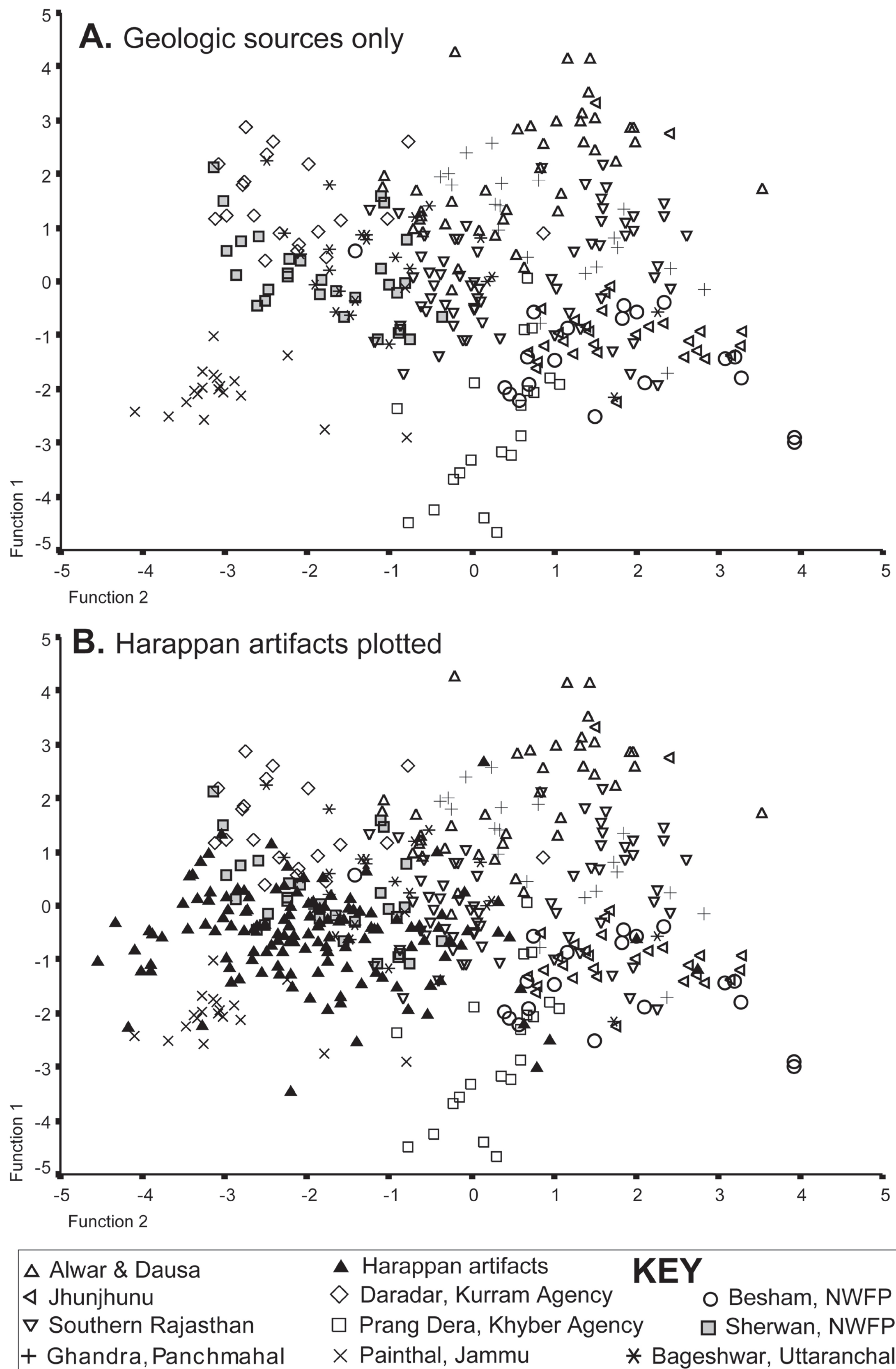
For **source key** see figures 7.2 and 7.22 A through D

larger groups to be compared, thus providing more statistically secure appraisals. Whereas in the subset of 23 dolomitic deposits no group had more than 20 members, the ten groups now in the set ranged in size from 20 (for the individual deposits) up to 65 members (for the southern Rajasthan group).

Figure 7.39 A shows the re-grouped geologic samples plotted according to their first and second discriminant functions. On Figure 7.39 B, the 139 Harappan artifacts are plotted as ungrouped cases in relation to the samples. The PGMs for this analysis are found in Appendix 7.1 and are summarized in Figure 7.37 under the column headings "regional dolomitic." Eighty-three artifacts were predicted to belong to the Sherwan group while 15, 15 and 16 artifacts were, respectively, assigned to the Daradar (Kurram), Prang Dera (Khyber) and Painthal (Jammu) deposits. Only ten artifacts were assigned to groups made up of samples from deposits in Rajasthan or Uttaranchal.

Repeated comparisons of the unfired steatite artifacts from Harappa to refined and/or regrouped versions of the geologic dataset produced PGMs that were largely consistent with one another from analysis to analysis. However, before simply using those as provenience determinations it is important to be mindful of a few things. First, in CDA each ungrouped case (artifact) is assigned a PGM regardless of its similarity or dissimilarity to any of the groups (deposits) within in a dataset. So in this study the possibility exists that one, several or even all of the artifacts do not actually belong to any of the deposits in the geologic dataset despite being assigned to one. Secondly, recall from the discussion of CDA in Chapter 3 that group membership is predicted based on an individual case's Mahalanobis distances to the various centroids of groups in a dataset. There is a chance that an artifact that genuinely belongs to deposit *A* will be predicted to belong to deposit *B* because it happens to lie closer (has a lower Mahalanobis value) to deposit *B*'s group centroid. The reason may be that the artifact is a distant compositional outlier of deposit *A* or because geochemical similarities between the deposits *A* and *B* have resulted in a degree of overlap among the individual cases making them up. Regarding the latter possibility, I would point out that the classification success rate for cross-validated grouped cases in the geologic set was, at best, around 80%. This indicates that although source discrimination was good, it was

**Figure 7.39** CDA comparison of regional dolomitic steatite source areas and Harappan artifacts.



far from perfect. It is for precisely this reason that I have provided the *second* highest group membership predictions (as determined by which group centroid has the second lowest Mahalanobis distance value) after the first PGMs with the results of the "parent-rock" analysis (in Appendix 7.1 this is written as "1st PGM / 2nd PGM" ). There is also a summary of these second PGMs in fifth column of Figure 7.37. As artifact provenience determinations are examined more closely below, these second PGMs will be helpful for considering possible alternative source associations.

In all the rounds of CDA, the first PGM for the majority of the artifacts from Harappa was one of the Sherwan zone deposits in the Hazara District, NWFP. The majority of that majority also had a second highest PGM in one of the Sherwan deposits. Because of this and because of the large number of assigned artifacts, I feel that this provenience association is a very strong one. Of the remaining artifacts assigned to Sherwan deposits, the second PGM for most was another one of the occurrences to the north of Harappa. Therefore, if any of those happen to actually not come from the Sherwan zone, there is a very good possibility they were derived from the "northern" region.

The provenience associations for artifacts assigned to the Prang Dera (LKPD) and Painthal (JAMPT) deposits appear, for the most part, to be fairly strong. Their numbers did not shift too drastically from analysis to analysis and around half of their second PGMs were deposits elsewhere in the "northern" region. On the other hand, some of them could be outliers of the Sherwan zone, like those assigned to Daradar (PD) perhaps are. In the first three CDAs, six to seven artifacts were predicted to belong to the Daradar source and the second PGM was in the Sherwan group for all but one of those cases. However, in the final regional-level analysis, nine additional artifacts, many of which had before been assigned to Sherwan, were designated as belonging to Daradar. This could indicate that a number of the artifacts assigned to Sherwan actually derive from other "northern" sources.

Turning now to the artifacts that had first PGMs in other regions, we see that very few (never more than three) were ever predicted to belong to occurrences in Uttaranchal. The second highest PGM for those cases in all analyses was the Sherwan Khanda Khu deposit (SKK). These are very likely compositional outliers from the Sherwan zone. The same is probably also true of many or all of the artifacts predicted to belong to southern Rajasthan deposits (from three to nine in various analyses). On the other hand, the ones assigned to occurrences in northern Rajasthan, although few in number, are somewhat more distinct and *may* be genuinely from that region. They often have second PGMs in the same zone and/or plot apart from the main body of artifacts in the scatterplots. Note, in particular, artifacts H2000/9445-1 and H96/7467-658 (both are identified on Figures 7.38).

Ultimately, it is probably best advised not to treat the PGMs made during the various CDA analyses as hard and fast provenience determinations. Although these predictions may oftentimes provide accurate information about the geologic sources of individual steatite artifacts, they are better (and more reliably) used collectively to reveal broad-scale patterns. When employed in this manner, they help to make a very strong case that most of the steatite acquired by Harappans probably came from sources to the north of their settlement, in particular, those in the Hazara District of the NWFP. Although I advise caution when treating PGMs as firm provenience determinations, I will use those from the refined "11 dolomitic sources" analysis in an upcoming dendrogram (Appendix 7.10) and two tables (figures 7.43 and 7.44) designed to facilitate detailed spatial and temporal examinations of steatite acquisition at Harappa. While doing so, however, close attention is paid to broad-scale patterns and the second PGMs of

potentially misclassified artifacts.

*- Cluster analyses*

Cluster analyses (CA) were performed on 140 unfired steatite artifacts from Harappa (all except the seal boss) in order to determine if they grouped ways that might shed additional light on the previous CDA and CA results and, ultimately, provide insights into the use of this rock variety at the site. Analyzing them alone (instead of with other artifacts and geologic samples) allowed better detection of potentially meaningful clusters among the assemblage. Multiple clustering strategies were used, all of which produced very similar dendrograms. The one in Figure 7.40 was made using the same complete linkage method that was used to make the dendrogram of the archaeological set and full geologic set (Figure 7.36). Four clusters (numbered "C1" through "C4") having members that joined between RDCC between 3 (C2) and 7 (C4) were defined. See Appendix 7.10 sections A and B for information (number, contextual data, type and PGM) on the individual artifacts making up the dendrogram.

The first thing to note is that, with the exception of C4, none of the clusters are entirely homogenous in terms of being made up of artifacts assigned by CDA to a single deposit or to a single geologic formation. This was not unexpected since that the cross-validation success rate for the analysis that supplied the PGMs ("11 dolomitic sources") was only around 80%. There was a good chance that some may have been misclassifications. As a result, compositionally related artifacts assigned different PGMs may have clustered together. Another point to note is that although I have defined four main clusters of artifacts, each does not necessarily correspond to single steatite deposit or even an extended zone of steatite formation. There could be artifacts from several unrelated sources represented within a single cluster or, conversely, a single, compositionally diverse source or source area may be represented by multiple

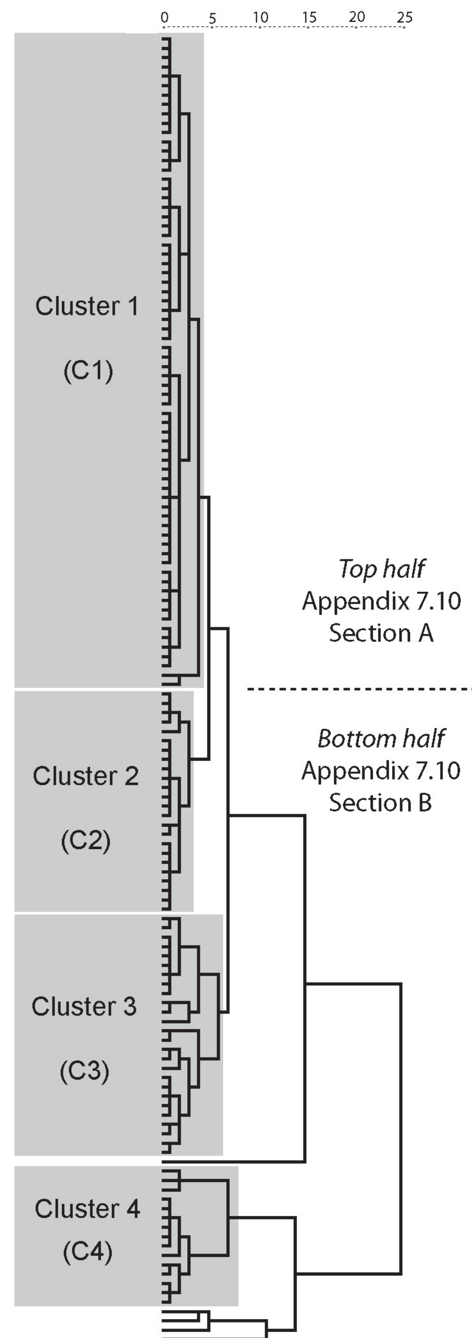



**Figure 7.40** Cluster Analysis (Complete linkage / squared Euclidian distance) of 140 steatite artifacts from Harappa

clusters. This should be kept in mind as I discuss how the artifacts are distributed in the dendrogram.

Cluster 1 (C1) encompasses the largest group of unfired steatite artifacts. It has 70 members, 56 of which have one of the Sherwan deposits as their first PGM. Of the other 14 artifacts in the cluster, ten are "northern" sources that have second PGMs of Sherwan so it is possible they actually derive from

that zone but were misclassified by CDA. Three of the remaining four were predicted to be from the Painthal, Jammu deposit (JAMPT). The final artifact in cluster has a first PGM in the Teori in deposit of northern Rajasthan (ATM) but may be an outlier of the Sherwan zone as indicated by its second PGM (which is SKK).

Eleven of the 15 artifacts predicted to belong to the Painthal deposit make up nearly half of the 24 members of Cluster 2 (C2). Nine of the remaining 13 are assigned to one of the Sherwan deposits. Three of those have a second PGM of Painthal, however. Two artifacts have a first PGM in the Shisha Khani (USK) deposit of Uttaranchal (with second PGMs in Sherwan) while one is assigned to Deola in southern Rajasthan (RDP).

Eleven of the 14 artifacts assigned by CDA to the Prang Dera deposit in the Khyber Agency (LKPD) are among the 26 members of Cluster 3 (C3). Twelve others artifacts in the cluster were predicted to belong to the Sherwan zone while the remaining three ones have Rajasthan deposits (ANB, RDP and RSA) as first PGMs.

All of the 15 artifacts making up Cluster 4 (C4) have first PGMs in the one of the Sherwan deposits and 13 of 15 of them also have second PGMs in that zone. This is the only homogenous cluster in terms of its members' predicted geologic proveniences.

There are also a few of smaller branches on the dendrogram that are distinct from the four primary clusters. Between C3 and C4 is a single artifact (H2000/9445-1) predicted to belong to Nangalhari-Bairaswas zone (ANB) of northern Rajasthan. Two of the cases in the final small cluster at the bottom of the dendrogram are the artifacts made from ultramafic steatite (discussed at the beginning of this section). Another case (H2000/9840-8) is a fragment assigned to the Sherwan Bandi (SB) deposit. When the ultramafic artifacts are removed and the same CA is performed on the set again (not shown) that particular artifact joins C4. The last artifact (H96/7467-658) on the dendrogram is assigned to the Teori (ATM) deposit of northern Rajasthan. Each artifact (except the ultramafic ones) is noted on the "11 dolomitic sources" CDA scatterplot (Figure 7.38).

The patterns exhibited by the dendrogram shown in Figure 7.40 and by others made using different clustering methods (not shown) helped to support and clarify and much of what CDA previously revealed about the set of dolomitic steatite artifacts from Harappa. Several artifacts that I had suspected were misclassified as belonging to deposits in Uttaranchal and southern Rajasthan were, in fact, shown to be compositionally similar to the numerous ones assigned to the Sherwan deposits and other sources to the north of the site. Others that were thought to genuinely come from sources outside of the "northern" region were confirmed to be compositionally distinct and likely unrelated to the majority of steatite used at Harappa. Although the PGM makeup of each cluster (except for C4) is mixed (no doubt due, in part, to misclassified outliers), artifacts predicted to belong to the same source or source area do have a tendency to group together (those assigned to Sherwan are found mainly in C1 and C4, to Painthal in C2 and to Prang Dera in C3).

Cluster analysis focusing solely on steatite artifacts from Harappa was necessary in order to gain a clear understanding of the compositional variability possessed that sub-assemblage. It is now possible to much better evaluate the distribution of those artifacts among the "main" clusters of the dendrogram generated in the CA of the archaeological set and full geologic set (Figure 7.36). To facilitate the examination of that dendrogram, the number for most of the Harappan artifacts appearing on it (Appendix 7.9) is preceded by the codes (C1 through C4) denoting the cluster that each belonged to in Figure 7.40.

On the full archaeological/geologic dendrogram (Figure 7.36 and Appendix 7.9) the artifacts that were

members of C1 and C2 in Figure 7.21 are entirely encompassed in a large, closely related sub-cluster of "main dolomitic cluster #2" (MDC#2) that extends from Section G to Section K and joins at RDCC 4 in Section I. Within that sub-cluster, C1 and C2 artifacts do remain, more or less, distinct from one another suggesting that may represent different deposits or, *perhaps*, different outcrops or veins within a single deposit (the latter possibility is discussed more fully below). The geologic samples encompassed in that same sub-cluster of MDC#2 include 19 of the 20 samples from the Painthal deposit but only eight of the 30 from the Sherwan zone. Recall that C1 was dominated by artifacts with a first PGM in one of the Sherwan deposits and about half of the artifacts in C2 were predicted to belong to the Painthal source with most of the rest assigned to the Sherwan zone. It could be that many of the C1 artifacts assigned to Sherwan actually belong to a source in the Jammu region. However, over half (11 of 20) of the geologic samples from the Daradar deposit are in the sub-cluster too as are six artifacts assigned to that deposit. This just serves to illustrate and remind that overlap for geologic sources is very much a concern at this level and so PGM assignments should be considered tentative.

Most (18 of 26) of the artifacts that had been in C3 group together in a small but closely related sub-cluster of, aptly enough, MDC#3, which runs from Section N to Section O and joins at RDCC 3. Ten artifacts in that cluster have the Prang Dera, Khyber Agency (LKPD) deposit at their first PGM and three others have it as their second PGM. Half of the geologic samples in that same sub-cluster are from that deposit and so it can probably be regarded as fairly strong association. Six of the remaining eight artifacts that were originally in C3 grouped with the C1 and C2 artifacts in the same large sub-cluster of MDC#2 described above. The last two C3 members, both of which were assigned to the Sherwan zone, grouped in a cluster with three Sherwan assigned members of C4 in a sub-cluster (in Section F) of MDC#2 different than the one described above.

All of the Sherwan assigned artifacts that had made up C4 (with the exception of the three members just mentioned) group in MDC#1 (section D and E). That cluster joins at RDCC 6 but most of the artifacts in it are in a sub-cluster that joins at RDCC 2. Also in MDC#1 is H96/7467-658, which had been in the small branch of compositionally distinct artifacts at the bottom of Figure 7.40. Although the Teori (ATM) deposit in the Alwar District of southern Rajasthan is its first PGM, its second PGM is Sherwan Banda (SB) so it could be related to the other Sherwan assigned artifacts also now in MDC#1.

The artifacts that were not in one of the four defined clusters on the 140 Harappan samples dendrogram appear on the archaeological / full geologic set dendrogram in both expected and unexpected ways. The BMAC steatite wig (H98/8668-2) falls in the "Main ultramafic cluster" (MUC) in a small sub-cluster with geologic samples from the Sakhakot-Qila ophiolite. There can now be little doubt that this object is made from stone of ultramafic origin (possibly from the deposit it assigned to) and is very different from the steatite typically used at Harappa. The other artifact that had been predicted to belong to an ultramafic source – H97-7784-27, now is an outlying member of a small sub-cluster in MDC#2 (Appendix 7.9 Section G) made up of samples from the Degota deposit (DGT) in northern Rajasthan and the Khanda deposit (GPM) in Gujarat. This artifact could actually be an unusual dolomitic steatite with ultramafic properties (high Co and Cr concentrations). However, the opposite may be true as it lies nearby two of the samples from ultramafic sources (from ZUN in the Muslimbagh ophiolite) that in CDA and CA have been shown to overlap with the dolomitic sources. The final two artifacts that were compositionally distinct outliers – H2000/9445-1 (assigned to ANB in the Alwar District) and H2000/9840-8 (assigned

**Figure 7.41** Artifact clusters with or more 10 members in each of the first three RDCC levels on the full archaeological/geologic set dendrogram (Figure 7.36)

| | RDCC 1<br># of members (section/s) | RDCC 2<br># of members (section/s) | RDCC 3<br># of members (section/s) |
|---|---|---|---|
| Clusters | 10 (G)<br>19 (H)<br>28 (H & I)<br>18 (I)<br>22 (J & K) | 10 (D)<br>10 (G)<br>11 (G & H)<br>19 (H)<br>47 (H & J)<br>11 (J)<br>24 (J & K)<br>11 (N) | 10 (D)<br>10 (G)<br>77 (G to J)<br>11 (J)<br>25 (J & K)<br>20 (N & O) |
| total | **5 clusters / 98 artifacts** | **8 clusters / 143 artifacts** | **6 clusters / 153 artifacts** |

to Sherwan Banda), both appear in MDC#3 but are still very distinct from both one another and the other artifacts in that cluster.

Before shifting focus from the evaluation of the CA results to their interpretation (in the next subsection), a few final observations need to be related about the way in which the geologic samples and the artifacts are distributed on the dendrogram of the full geologic and archaeological steatite sets (Figure 7.36 and Appendix 7.9).

To begin with, steatite artifacts (from Harappa and the other sites) tend to group in clusters of cases that are far more closely related to one another than most groups of geologic samples collected from individual steatite deposits. For example, in Section H and I there is a cluster containing 28 artifacts that are all joined at RDCC 1. In other words, they are as compositionally similar to each other as cases depicted on the dendrogram can possibly be. Twenty-five members of that cluster were predicted to belong to one of the Sherwan zone deposits (and the three that were not had second PGMs in that zone). There are many other groups of artifacts like that one. Figure 7.41 is a table listing all of the artifact clusters with ten or more members that join in each of the first three RDCC levels. I chose to define clusters of ten both because it was a good round number and it was close to the average number of geologic samples analyzed per source (n = 11.9). Well over half of the 177 cases in the archaeological set are encompassed in just five clusters at RDCC 1. At RDCC 2, more than four-fifths of the artifacts group together in just eight clusters. One large cluster containing 77 artifacts and five smaller ones are formed at RDCC 3.

To appreciate just how closely related large groups of steatite artifacts are to one another it is only necessary to compare them to the clusters formed by geologic samples from individual deposits. For instance, the 20 samples collected from Prang Dera (PD) in the Khyber Agency are distributed widely across dendrogram (from section G to section N). The various sub-clusters they appear in do not join into a single cluster until RDCC 16. That level of similarity (or dissimilarity) is typical of the geologic deposits in the dataset. Figure 7.42 is a table in which the 37 deposits are listed according to the RDCC level at which all of their members are joined in a single cluster. The average level at which the deposits form complete clusters is 17.8. The only sources whose members all join at RDCC 1 are the Dev Pura (RDV) and Khadi Ghati (RSH) deposits of southern Rajasthan. None of the others join into a single cluster until RDCC 6 or higher. The majority of the deposits in the geologic set (20 of the 37) do not, in fact, completely join until RDCC 25.

The differences in how steatite artifacts tend to cluster versus how samples from steatite deposits typically cluster are striking. The way the latter are

**Figure 7.42** Rescaled distance cluster combine (RDCC) values at which all samples from a given geologic deposit can be encompassed into a single cluster on Figure 7.36.

| ***RDCC*** | **1** | **6** | **7** | **8** | **9** | **11** | **13** | **16** | **25** |
|---|---|---|---|---|---|---|---|---|---|
| ***Geologic source*** | RDV<br>RSH | KOT | RKA | JAMPT | ZTT<br>CHT<br>DMK<br>LBW1<br>RKG<br>RMP<br>RSB | PD | JKK | LKPD<br>SB<br>RSA | ANB<br>ASN<br>ATM<br>BESH<br>DGT<br>GPM<br>JJC<br>JJG<br>RDP<br>RRA<br>SC<br>SKK<br>UB<br>USK<br>US<br>LBW2<br>RST<br>ZTAK<br>ZUN<br>RRD |

dispersed on the dendrograms actually helps to clarify why certain artifact provenience assignments (PGMs) may be distributed in the manner that they are. For example, on both the full sets dendrogram (Figure 7.36 and Appendix 7.9) and on that for the 140 artifacts from Harappa (Figure 7.40 and Appendix 7.10), artifacts assigned to the Sherwan zone appear in every major cluster (except the MUC on Figure 7.36). Some of those clusters (C4 on Figure 7.40 and MDC#1 in Figure 7.36) are quite distinct from most others. This *could* indicate that the artifacts making them up, although they have the same PGMs as those in the other clusters, are from a different source(s). However, it is now clear that samples from most of the individual geologic deposits possess a significant degree of internal geochemical variability and are dispersed in a way not unlike the PGMs. It is very possible, therefore, that artifacts having the same PGM assignments but appearing in different clusters are indeed actually from the same geologic source. Still, the possibility that the compositionally distinctive Harappan artifacts comprising C4 in Figure 7.40 and again appearing (mostly) in MDC#1 on Figure 7.36 (and later in section D of Figure 7.46) are from a source different from that of the other archaeological samples in the set should be kept in mind as discussions of steatite acquisition take place in the next section.

The different clustering patterns for the archaeological and geologic steatite samples have also provided a potentially important insight into the exploitation and use of that variety of stone in antiquity. The large clusters of closely related steatite artifacts could conceivably represent groups of raw material from single geologic occurrences. However, as has just been discussed, few geologic deposits in the dataset even approach having the same level of compositional homogeneity as exhibited by the artifact clusters. I therefore submit that those clusters possibly represent raw material exploited from a very restricted area *within* an individual steatite occurrence, such as a single vein, pit or mine.

When I visited a steatite source for this study I had two objectives: 1) to collect examples of Harappan-quality stone and 2) to obtain the widest range (in terms of spatial distribution and

macroscopic appearance) of that material as possible so as to document the geochemical variability of the deposit. With regard to the latter objective, I seem to have succeeded (judging from the dispersed geologic samples and the overlap between sources). The closely related groups of artifacts in the archaeological set may indicate that when Harappans (or their suppliers) visited a steatite source their objective was to acquire a specific kind of material, rather than just any seemingly good-quality stone found there. If they had been obtaining a wider variety of material from across a deposit or zone then the clustering patterns among the artifacts might be expected to look more like those of the geologic sources. Although we cannot be certain that of the all artifacts in a closely related cluster actually came from one source, the exploitation of a very specific kind of stone would fit with what I argue to have been a primary concern for Harappan craftspeople, which was the acquisition of steatite that becomes white when heat-treated.

*- Interpretation of the results*

The 621 unfired steatite artifacts and geologic samples examined in this chapter constitute the most complex dataset in of this entire study. The painstaking series of analyses and evaluations detailed in the preceding section were necessary in order to get to the point where the predicted group memberships of artifacts could be confidently interpreted and used to form responses to the lines of inquiry outlined in Chapter 1.

Figures 7.43 and 7.44 are tables designed to facilitate the detailed temporal and spatial examination of the steatite artifacts from at Harappa. They were created using the 139 PGMs from resulting from the "11 dolomitic sources" CDA analysis (Figure 7.19 / Appendix 7.1 column 8) and the two PGMs for Harappan artifacts from the ultramafic parent-rock CDA (Figure 7.16 A / Appendix 7.1 column 7). When the results of the two analyses were combined, a total of 13 geologic deposits had artifacts assigned to them. These deposits are listed alphabetically by source code (see Appendix 7.2 column 4) in Figure 7.43 and are cross-referenced with the macroscopic types and general contexts (mound and period) of the artifacts assigned to them (surface and off-mound contexts were not noted this table). Type and contextual data for the artifacts are also found on the reproduction of the 140 Harappan artifacts CA dendrogram (Appendix 7.10), which is also referred to in this examination. Several of the source codes are followed by an asterisk and the notation "actually Sherwan?" For reasons explained in the preceding section, I consider it likely that the handful of artifacts assigned to southern Rajasthan and Uttaranchal are actually from one of the deposits in the Sherwan zone. Some of those assigned to the Daradar (PD) deposit could be as well and so I have noted those along with the others.

In Figure 7.44, the PGMs for all 141 artifacts from Harappa are cross-listed by the area and period from which they were recovered. Multiple artifacts from one source are indicated by a "times" sign and number (e.g., SB x 4 = four artifacts from Sherwan Bandi).

Type associations

Before beginning the discussion of steatite acquisition at Harappa, the macroscopic categories or "types" (Figure 7.4) that were used to classify unfired artifacts at the site are briefly considered in relation to the CDA predicted group memberships and the CA results. As I began to suspect while still collecting geologic samples for this study, there appears to be no clear relationship between the various "types" of raw steatite and sources of that stone (at least those that are in the geologic dataset). The second column of Figure 7.43 shows which of the seven types (A through G) are associated with each of the 13 deposits to which artifacts were assigned None of them appear exclusively with any one source or source area (such as the Sherwan zone). In fact, each is associated

**Figure 7.43** The 13 PGMs for the 141 steatite artifacts from Harappa and their type / contextual associations (surface and off-mound contexts not noted). See text and Appendix 7.2 for source codes.

| **Source** (# of artifacts) | **Types** | **Periods** | **Mounds** |
|---|---|---|---|
| ANB (2) | F, G | 3B, 3C | AB, F |
| ATM (2) 1*actually Sherwan? | A | 1* | AB |
| JAMPT (14) | A, B, C, E | 1, 2, 3A, 3B | AB, E |
| KOT (1) | F | 3C | F |
| LBW1 (1) | A | 3A | AB |
| LKPD (13) | A, B, C, F, G | 2, 3A, 3B, 3C, 4/5 | AB, E, ET, F |
| PD (8) *actually Sherwan? | A, B, C, E, F | 2, 3B, 3C | AB, E, ET, F |
| RDP (2) *actually Sherwan? | A, D | 2, 3C | AB, ET |
| RSA (2) *actually Sherwan? | A, E | 3A, 3C | AB, F |
| SB (41) | A, B, C, D, E, F, G | 2, 3A, 3B, 3C | AB, E, ET, F |
| SC (16) | A, B, E, F, G | 2, 3A, 3B, 3C, 4/5 | AB, E |
| SKK (38) | A, B, C, D, E, F | 2, 3A, 3B, 3C | AB, E, ET, F |
| USK (2) *actually Sherwan? | A | 3A | AB |

**Figure 7.44**: Spatial and temporal distribution of the PGMs for the 141 artifacts from Harappa

| ***Period →*** **Mound ↓** | ***1*** | ***2*** | ***3A*** | ***3B*** | ***3C*** | ***4/5*** | ***surface & disturbed*** | ***total*** |
|---|---|---|---|---|---|---|---|---|
| **F** | *not present* | *not present* | *not present* | PD*<br>SKK | ANB<br>KOT<br>LKPD<br>RSA*<br>SB x7<br>SKK x2 | *not sampled* | *not sampled* | *15* |
| **AB** | ATM*<br>JAMPT | JAMPT x6<br>LKPD<br>PD*<br>RDP*<br>SB<br>SC x 5<br>SKK x 2 | JAMPT<br>LKPD x2<br>LBW1<br>RSA*<br>SB x2<br>SC x3<br>SKK x9<br>USK x2* | ANB<br>JAMPT<br>SB x3<br>SC x4<br>SKK x2 | SB<br>SC | LKPD<br>SC | ATM<br>SC<br>SKK | *58* |
| **E** | *not sampled* | JAMPT | JAMPT x2 | JAMPT x2<br>LKPD x2<br>SB x1<br>SKK x2 | LKPD x3<br>PD x2<br>SB x5<br>SC<br>SKK x5 | *not sampled* | JAMPT<br>LKPD<br>PD*<br>SB x 6<br>SKK x3 | *38* |
| **ET** | *not present* | *not present* | *not present* | SKK | LKPD x3<br>PD x2*<br>RDP*<br>SB x6<br>SKK x7 | *not sampled* | SB x3<br>SKK | *24* |
| **cemetery & off mound** | *n/a* | *n/a* | *n/a* | *n/a* | SB x4 | *n/a* | SB<br>SKK | *6* |
| **total sampled** | *2* | *18* | *23* | *21* | *54* | *2* | *21* | ***141*** |

with at least three different deposits. Artifacts of the same "type" also seem to be, for the most part, highly variable compositionally. A perusal of the type codes listed next to terminal ends of the Harappan artifact dendrogram (Appendix 7.10) indicates that, aside from one or two minor areas (such as where six Type F artifacts fall together in Cluster 2), each type is distributed widely among the four clusters. Of course, samples from most of the geologic deposits are similarly distributed and so it is *possible* that artifact of a particular "type" come from the same source. Even so, these findings suggest it is very unlikely that the macroscopic appearance of unfired steatite artifacts (at least of those from Harappa) can provide reliable information about their geologic provenience.

Addressing the three lines of inquiry

The CDA and CA results are now brought to bear on the three lines of inquiry – the first being: *With whom were residents of Harappa interacting when acquiring steatite? What was the extent of those inter-regional interaction networks during different periods?*

The results of this study indicate that acquiring of most of the steatite used at Harappa would have entailed either direct or indirect interaction with non-Indus Civilization cultures dwelling in the highland region 330 to 445 km north of the city. Around 89% of the 141 steatite artifacts analyzed were predicted to belong to one of seven geologic sources in that region (JAMPT, KOT, LKPD, PD, SB, SB or SKK). When those artifacts that were likely misclassified as belonging sources in southern Rajasthan and Uttaranchal are factored in, the percentage is almost 95%. These percentages, and the others reported in this section, were generated by averaging the first PGMs of the four reported CDAs (listed in the last four columns of Appendix 7.1). When I discuss the provenience of specific artifacts I am relying on the PGM made from the "11 dolomitic sources" CDA unless otherwise stated.

Of the artifacts assigned to "northern" sources, around 69% (61% of the total from Harappa) appear to be most closely related to steatite from occurrences in the Sherwan zone of the Hazara District (SB, SB and SKK), which are around 50 to 60 km north-northwest of the Kot Dijian settlements of Hathial and Sarai Khola. Among these is the unfinished steatite stamp seal (H96/7257-46) pictured in Figure 7.5 A. Approximately 13% were predicted to belong to the Painthal deposit in Jammu, which is just 25 km from the Early Harappan and Harappan site of Manda. The bead blanks (H2000-2301-176 & 177) pictured in 7.5 C & D are assigned to this source. Another 11% of the artifacts assigned to "northern" sources had first PGMs of the Prang Dera source, Khyber Agency. However, it may be that around half of those may actually belong to the Sherwan zone as *perhaps* some or all of the roughly six percent assigned to the Daradar, Kurram Agency source do. The final artifact from Harappa assigned to a "northern" source is the BMAC steatite wig (Figure 7.5 E). Its first PGM, both when compared to the full geologic set and just to the ultramafic deposits, is the Sakhakot-Qila ophiolite (KOT) in the Mohmand Agency, FATA.

A few dozen sites belonging to the cultural phase that Stacul calls (1992, 1994) the "Inner Asian Complex" and that Possehl refers to as the "Northern Neolithic" (1999: 542-553) have been identified across the same general region where many of the "northern" steatite deposits are found. It is with the highland-dwelling farmers and pastoralists of this culture that residents of Harappa would have interacted with, either directly or indirectly, to obtain much of their steatite. Kot Dijian items found at Northern Neolithic sites in the Swat (Stacul 1987) and Kashmir (Saar 1992) valleys provide clear evidence for contacts between those highland and lowland peoples. Although the nature of those contacts is not known, there are several possible scenarios with regard to steatite acquisition.

1) Northern Neolithic peoples could have been

the ones who extracted steatite and transported it to the Punjab; perhaps along with some of the other raw materials that I later show also likely came from sources in the north such as vesuvianite-grossular (Chapter 9), alabaster (Chapter 10) and lead ore (Chapter 12). Although they primarily inhabited the mountain valleys of northern Pakistan and India, it is certainly not out of the question that they may have traveled to the south. Possehl reports (1999: 548) having identified Northern Neolithic sites near Leiah in the Thal Desert of the western Punjab. However, no items clearly related to that culture have yet been discovered at Harappa.

2) Northern Neolithic peoples might have mined steatite and then transported it only as far as the nearest Early Harappan or Harappan settlement. From there, the raw material could have been moved through internal Indus trade networks to sites in the south like Harappa while Indus trade goods (carnelian beads and Kot Dijian-style ceramics) could have been acquired and brought northward to the Northern Neolithic sites where they have been found. Hathial, Sarai Khola, Manda, Ropar and other settlements in the foothills and/or on the plain at the base of the Himalayas were certainly well-positioned to be nodes where this type of exchange between highland and lowland cultures could take place. However, it has never been established if such sites actually functioned as trading outposts.

3) A person or a group from Harappa (or another Early Harappan/Harappan site) could have traveled to the northern highlands and extracted steatite themselves from one of the sources found there. This still would have entailed some form of interaction with local populations. Importantly, it also would have permitted them to judiciously select raw material having properties that they (or their fellow Harappans whom they were supplying) desired. As I suggested above, the groups of steatite artifacts that are highly related to one another compositionally may represent stone extracted from the same vein, pit or mine shaft within a larger individual occurrence or zone. I also suggested that this focus on material from a restricted area (rather than from an entire deposit), if it is genuine, is probably indicative of the desire by Harappan craftspeople to acquire a very specific kind of steatite that turns white upon being heated. The macroscopic appearance of raw steatite does not provide any indication of what color it will become after being fired (*personal observations* discussed below). Therefore, the identification of areas where white-firing stone occurs within a deposit almost certainly would have involved some amount of experimental heating. Northern Neolithic peoples appear to have used very little steatite themselves (Pande [2000] reported that just eight of the 1488 beads recovered at Burzahom are made from steatite) and, as far as we know, none were heat-treated. Although this does not necessarily mean that those northern peoples would have been unable identify and exploit bodies of white-firing steatite, Harappans, with their advanced pyrotechnological capabilities and intimate knowledge of this variety of stone, were likely far more adept at it.

The scenarios above are not the only ones that could account for how raw steatite from "northern" sources was acquired by craftspeople at Harappa. Variations of all three could have taken place, either simultaneously or at different times. Perhaps an unknown third party was involved (Scenario #4). However, short of discovering artifacts at a mining site that are clearly associated with a cultural phase (Harappan or some other one) it is almost impossible to do more than speculate about who actually did the work of extracting the stone. Issues relating to exchange between highland and lowland cultures at settlements that may have been trading outposts cannot be addressed until further question-oriented excavations are conducted at such sites. With regard to the transportation of the stone, we really can talk only about whether or not the sources that appear to have been exploited are internal or external to the area

encompassed by Early Harappan/Harappan cultures. Even then we must be cautious because, as Smith has pointed out (2005), models of cultures as bounded, homogenous socio-political entities are often based upon cartographic illusions.

Putting aside interpretive considerations for the moment, the above results constitute clear and compelling evidence for interaction between residents of Harappa and peoples in the highlands to the north of the site, especially those in the Hazara District and Jammu. It is unlikely to be a coincidence that (Late) Kot Dijian and/or Harappan sites are found in the same general vicinity as steatite deposits in those regions. Some degree of interaction with groups in the Kurram and Khyber agencies is also indicated. However, there are sources in Hazara (like the Khangar Dhaka deposit in the Sherwan zone) and in Jammu (multiple deposits in the vicinity of Vaishno Devi) that, when eventually analyzed, could be found to be the actual sources of some or all of those artifacts assigned to deposits in the FATA.

On that note, it is important to again acknowledge that the PGMs made here could change, perhaps drastically in some cases, as samples from more deposits are incorporated into the geologic dataset. In this regard, artifacts to be mindful of in future analyses include those making up the compositionally very distinct cluster number four (C4) in the 140 Harappan artifacts dendrogram (Figure 7.40). All are assigned to one of the Sherwan deposits but they do not join the other artifacts assigned to that zone until RDCC 25 (this is also true of most of those same artifacts on the full sets CA dendrogram [Figure 7.36]). I have discussed above how it is possible for artifacts to be from the same source but end up in very different clusters. This could be one of those instances. However, in an upcoming dendrogram it is evident that "C4" artifacts are *somewhat* more closely related to a similarly distinct group of artifacts from the site of Mehrgarh than they are to most of the others from Harappa (Figure 7.46). There is the possibility, therefore, that they might have been derived from an unsampled deposit in Balochistan. Only future analyses will tell.

One final artifact that was initially predicted to belong to a deposit in the highland region north of Harappa remains to be discussed. It is the BMAC steatite wig from Period 3C, which is assigned to the Sakhakot-Qila ophiolite source. Its PGM is important for two reasons. Firstly, it supports the stylistic evidence that indicates the wig is a non-Harappan object by showing that it was created from ultramafic steatite – a type rarely used by Harappans. Just one other unfired steatite object at Harappa (or at least just one other among the 4.68% of the sub-assemblage that was analyzed) and only a few from any of the other Indus Tradition sites in the archaeological sample set are composed of material of ultramafic origin. Secondly, this finding provides (or can provide) information about the avenues through which Harappans interacted with the Central Asians who probably made and used the wig. Evidence from Mehrgarh Period VIII and elsewhere suggests that BMAC peoples were entering the Sindh region via central Balochistan around the turn of the first millennium BC (Jarrige 1991a; Parpola 2005: 267). However, there are other routes from Central Asia and Afghanistan along which they could have traveled into the Indus Valley. If the wig is actually made from Sakhakot-Qila steatite then it would suggest that one of those alternate routes was through Peshawar Valley via one of the many passes (Khyber, Malakand, Bajaur) that connect it with regions to the west and north.

It is possible, however, that the wig is made of steatite from a different source. When it is compared to a refined geologic set (Figure 7.45) that includes the deposits that were its original first and second PGMs – Sakhakot-Qila (or KOT – 1st PGM) and Zhob Tor Tangi (or ZTT – 2nd PGM), it is re-assigned to its initial second PGM. So the wig *could* actually be from an ultramafic source in north Balochistan. This

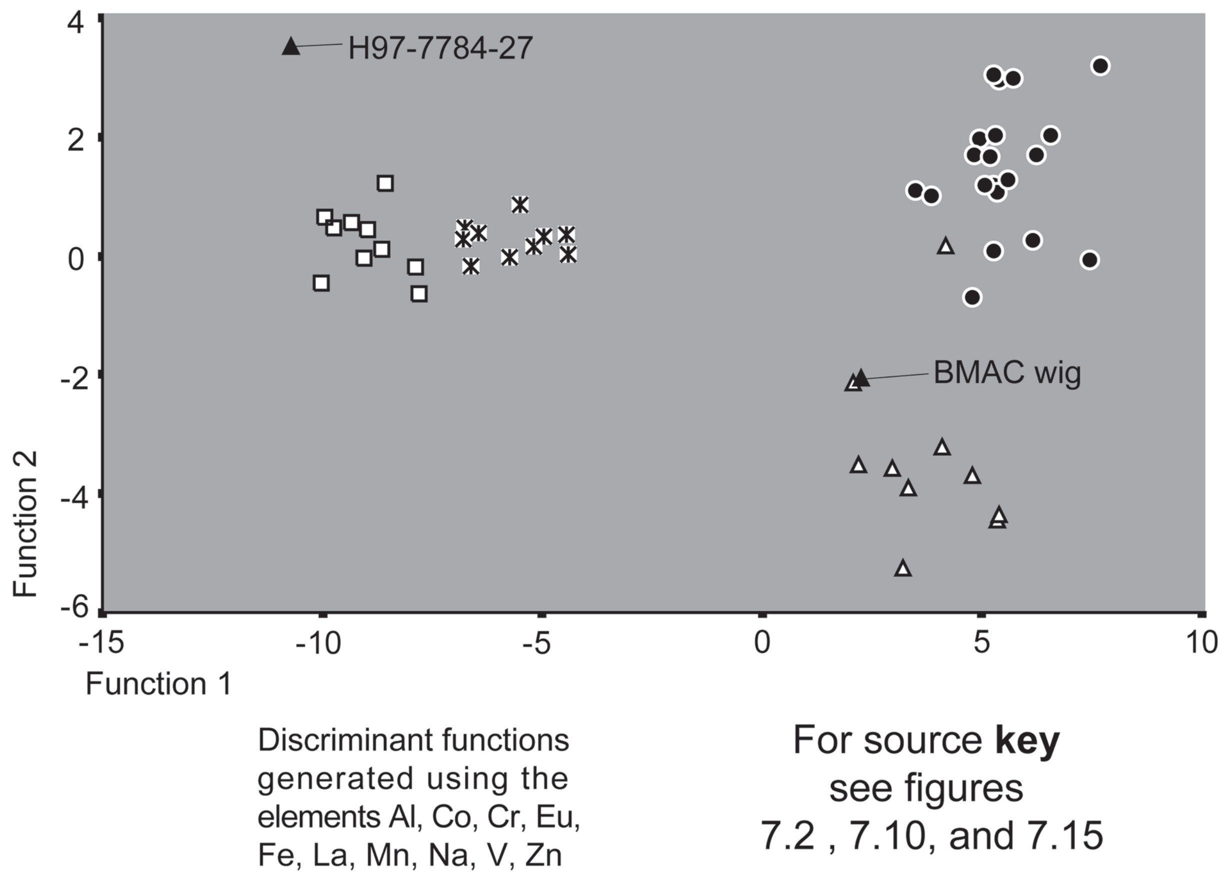



**Figure 7.45** The two ultramafic steatite artifacts from Harappa compared to select ultramafic sources.

would still support the interpretation that it is a non-Harappan object although it might now indicate that BMAC peoples were indeed entering the Indus Valley via Balochistan rather than the NWFP. It is also possible that the steatite used to make the wig comes from a different source altogether, perhaps one nearer to the BMAC homeland, which, of all of the deposits in the geologic set, happens to be compositionally most similar to the ones at Sakhakot-Qila and Tor Tangi. The INAA results for the wig indicate that clearly the place to search for that deposit would be in an ultramafic formation, probably an ophiolite.

On average, only around five percent of the 141 steatite artifacts analyzed from Harappa appear as if they might be composed of raw material from sources outside of the region to the north of site. One of these is artifact H97-7784-27 – a yellowish gray (Type A) sawn fragment from Period 3A workshop debris exposed in Trench 42 on Mound AB. It is the only steatite object analyzed from Harappa other than the BMAC wig that appears to be of ultramafic origin. Although it does not resemble the distinctive type of green steatite with black spots that is so well-known in Pakistan today, it was predicted to belong to the same group of samples of that stone that were obtained from the Duddo mine (LBW1) in the Wayaro area, Las Bela District, Balochistan. Recall that this deposit is located less than 20km from Bakkar Buthi where there is an Indus Civilization phase equivalent to Period 3A and 3B at Harappa (Franke-Vogt *et al.* 2000: 199) and so it might then have been directly accessible to the Harappans living there.

There is, however, a good possibility that the raw material this artifact is composed of did not come from the exact deposit to which it has been assigned. When it is compared to a refined geologic set (Figure 7.45) that includes the deposits that were its original first and second PGMs – Duddo mine (or LBW1 – 1st PGM) and Thaddi mine (or LBW2 – 2nd PGM), it is re-assigned to the Thaddi deposit, which is only

about 5 km away from Duddo. Note, however, that the artifact appears distinct (plotting away from) from both deposits. It may be that it was quarried from one of the many old pits and worked shear zones that I observed in the area rather than the modern mines. Or it might be from another occurrence. Although I have found no references to other deposits in the geologic or historic literature, the Las Bela ophiolite extends from the Wayaro area northward over 100 km, past Kulli culture settlements like the Edith Shahr complex (Fairservis 1975) and Nindowari (Casal 1966). The artifact could conceivably be from a geologically related steatite occurrence that was nearer to the ancient peoples of those sites. In any case, of all of the ultramafic deposits in the geologic set it is still most closely related to those from southern Balochistan.

Between four and ten artifacts from Harappa were, depending on the CDA results, predicted to belong to steatite sources in the Jhunjhunu and Alwar districts of northern Rajasthan. Like those originally assigned to Uttaranchal and southern Rajasthan deposits, many have second PGMs in one of the sources to the north of the site and could be, in fact, from that region. Artifact H96/7531-16 – a small fragment from Period 1, is one of these that are *perhaps* a misclassified outlier. It is noted "*actually Sherwan?" on Figure 7.43.

A few artifacts that were predicted to belong to a northern Rajasthan deposit appear on the CA dendrograms to be compositionally distinct from the majority of the other artifacts in the set, which is say that they are very different from most of the ones assigned to the Sherwan zone and other "northern" sources. The cylindrical bead (H96-7467-658) made of black steatite pictured in Figure 7.5 B was one of these. Although in the full set CDA it was assigned to the Sherwan zone, in the later refined 11 dolomitic sources CDA it was predicted to belong to the Teori (ATM) deposit in the Alwar District. Other similarly distinct artifacts include fragments H99/8760-77 and H2000/9445-1, both of which were assigned to the Nangalhari-Bairaswas zone (ANB). These, and the few others like them, may indeed be from deposits in northern Rajasthan (including some in Jhunjhunu). The presence of steatite at Harappa that is genuinely from that region would constitute evidence for interaction with peoples of the Ganeshwar-Jodhpura complex. However, it is possible that some or all of these artifacts actually are from a source or sources that are not in the geologic set. On the full sets CA dendrogram (Appendix 7.9), the artifacts noted in this paragraph, although assigned to northern Rajasthan deposits by CDA, do not actually cluster with or nearby any geologic samples from that region.

Next, the PGMs for the Harappan artifacts are used to address the question: *Did the patterns of steatite acquisition exhibited by residents of Harappa change over time?*

Based on a preliminary study conducted in 2003, I reported (Law 2005a: 118-119) that a significant diachronic shift in source utilization was evident in Harappa's unfired steatite artifact assemblage. I had interpreted four major clusters on a CA dendrogram to be roughly equivalent to individual sources or source areas. Two clusters, one of which was composed largely of artifacts predicted by CDA to belong to the Sherwan (Hazara) zone and the other of artifacts assigned mostly to the Prang Dera (Khyber) deposit, seemed to have been utilized mainly during the Early Harappan period. The two other major clusters, which at the time I thought might have represented sources in Jammu that had not then been analyzed, seemed to have been exploited mostly during the Harappan period.

Based on the CDA PGMs and the CA dendrograms produced for the current study, which involved additional archaeological samples and a substantially enlarged geologic dataset, I have concluded that diachronic changes in steatite acquisition patterns at Harappa are not nearly as significant as they were reported to be in 2003. In fact,

I would now characterize source use as remarkably consistent throughout most, if not all, of the site's prehistoric sequence. There were no increasing or decreasing trends in the exploitation of certain sources such as are evident for grindingstone (Chapter 5). Nor was there any dramatic shift in material source/type use like that which is evident for chert (Chapter 6). Although there were some changes over time, for the most part they were very minor. The steatite assemblage is dominated in every period by raw material from sources north of the site. Thus, the acquisition networks appear to have been stable and mostly unidirectional.

Steatite acquisition through time can be examined using figures 7.43 and 7.44. Deposits in the Sherwan zone (SB, SC and SKK) were being accessed at least by Period 2 (some perhaps as early as Period 1 – discussed below) and they continued to be the primary sources of the stone through Period 5. The use of raw material from the Khyber Agency (LKPD), although evidently much less intense, follows the exact same temporal pattern. Steatite from Jammu (JAMPT) was used steadily from Period 1 through Period 3B. Its apparent absence in Period 3C simply may be due to it being missed in sampling. The 53 artifacts analyzed from that period represent only a 3.81% sample of the temporal sub-assemblage of material (Figure 7.6 B). However, it could be that acquisition of steatite from Jammu (or at least from the Painthal deposit) actually ceased after Period 3B. Regardless, all of these steatite provenience associations demonstrate that residents of Harappa were involved in early and sustained interaction networks with peoples (either Harappan or non-Harappan) dwelling in the region to the north of the site.

Steatite artifacts predicted to belong to deposits in Uttaranchal, southern Rajasthan and even some of those assigned to northern Rajasthan and the Kurram Agency, are very likely misclassified outliers of the Sherwan zone. Their firsts PGMs are left unchanged on figures 7.43 and 7.44 but their doubtful statuses are noted with asterisks. One artifact (H96-7531-16) with a questionable PGM is from Period 1. It was predicted to belong to Teori (ATM) in northern Rajasthan but *may* actually be a Sherwan outlier as it was assigned to that zone in the regional-level CDA. Even if it is actually from northern Rajasthan or another source area outside of northern Pakistan/India, Harappa's raw steatite assemblage during the Ravi Phase was, regionally speaking, as diverse as it ever would be.

The remaining few steatite artifacts from sources other than the main dolomitic ones in the north are found during Harappa's urban phase (Period 3). In addition to the BMAC wig and the artifacts that may be from northern Rajasthan, there is the ultramafic fragment from the Period 3A workshop on Mound AB that was predicted to be from the Wayaro area of southern Balochistan. The presence of steatite from this distant source (800 km southwest of Harappa) during Period 3A is not particularly surprising. At that time, Harappans were living in the vicinity (< 20 km away) of the deposit itself and marine shell (Kenoyer 1984b) and salted fish (Belcher 2003) were being transported from the nearby Arabian Sea coast. Steatite from southern Balochistan in a Punjab workshop is just another piece of evidence showing that the long-distance internal exchange networks characteristic of the Indus Civilization were firmly in place by that time. What is surprising is the rarity of this high-quality material. The 18 fragments analyzed from the Period 3A workshop represent an almost 10% sample of the steatite recovered from it. Had craftspeople there used raw material from Wayaro to a significant degree then chances are that at least a few more examples would have been sampled and identified. There is also the question of why, evidently, urban phase Harappans did not continue to acquire and use this kind of steatite. As is shown in my provenience study of lead artifacts (Chapter 12), raw materials from the southern Balochistan region

were being transported to Harappa through the end of Period 3C. The reason why Wayaro steatite did not continue to be used probably lies with the physical properties of the material rather than the distance to its source. Although it is excellent stone for carving and sawing, it will not fire to the white color that was preferred by Harappan consumers of steatite items (discussed in the final section of this chapter).

The final question is: *Did synchronic variations in patterns of steatite acquisition exist between groups of people living in different habitation areas at Harappa?* The answer to that question is: evidently not – at least not any major ones. By and large, craftspeople at Harappa all seem to have had access to the same sources of steatite regardless of where they lived and worked within the settlement. When the PGMs on figures 7.43 and 7.44 are considered on the regional level, the chronological sub-assemblages for all mounds either entirely (usually) or predominately (occasionally) consist of artifacts from the broad source area 330 to 445 km north of the city. That is, of course, to be expected given that about 95% (if potential misclassifications are factored in) of the artifacts analyzed were assigned to deposits in that region. When source use is considered on the level of individual deposits and zones, there does at first appear to be some variation among mound sub-assemblages during the certain periods. However, most synchronic differences can be explained by some form of sampling bias. The very small sample sizes (just one or two artifacts each) for Mound E during periods 2 and 3A, mounds F and ET during Period 3B and Mound AB during Period 3C, almost assuredly do not capture the full range of raw material sources used in those areas at those times. For example, on average, around 16 artifacts each were sampled from the Period 3C levels of mounds F, E and ET. Six different deposits are represented among the artifacts on each of those mounds. Only two deposits are represented on Mound AB. I strongly suspect that when the Period 3C sample from Mound AB is eventually brought up (from its current size of two) to the level of the other mounds its assemblage will appear just as diverse as theirs. Also, the reason that some chronological mound sub-assemblages do not contain artifacts assigned to the Prang Dera (LKPD) source, which, overall, is widely distributed both temporally and spatially, is likely because of that deposit's low (≈ 11%) representation among the total analyzed assemblage. Artifacts having that PGM were fewer and more likely to have been missed in sampling. Ultimately, it comes down to this – assemblages in areas where a good-sized sample was obtained are fairly diverse in terms of their PGM compositions while those in areas where a small sample was obtained are not. Rather than interpret the differences as possibly genuine, I provisionally consider steatite source usage across Harappa to have been, more or less, synchronically consistent.

Having said that, the artifacts assigned to deposits outside of the "northern" region do provide some indication that craftspeople working in certain parts of Harappa might have had access to sources of raw material apart from those used by most other residents of the site. However, because such artifacts are so few in number, they must be interpreted cautiously. For instance, it would be a considerable stretch to argue that residents of the mounds where steatite fragments assigned to northern Rajasthan were recovered had exclusive access to and/or somehow controlled the raw material from that region, even if such artifacts might have been found only in the areas where they lived/worked. There are simply too few of them to confidently make such statements. Still, a close examination of artifact PGMs and their contextual details listed in Appendix 7.1 suggests that there might have been areas of the Harappa where, at certain times, some of the rarer kinds of steatite were used to a fairly significant degree. One of these areas is Mound F during Period 3C. In Trench 41, three fragments (H99/7636-8, H99/7637-32 and H99/7638-1) recovered from a group of Period 3C

rooms adjacent to the city wall are possibly from northern Rajasthan even though they were not assigned to that region in the "11 dolomitic sources" CDA (in most of the other CDAs the three were assigned to one of the Jhunjhunu deposits). Not far away in Trench 43, a fragment predicted to belong to the Nangalhari-Bairaswas (ANB) zone was also found. In total, 13 of the 63 unfired steatite artifacts recovered from Period 3C levels of Mound F were analyzed and, of those, four might be from a source in northern Rajasthan. If this is an indicative sample of the mound then perhaps around one-quarter to one-third of the steatite acquired by craftspeople working there might have come from that region 400 to 500 km southeast of the site. Recall from Chapter 5 that it was also on Mound F where most of the Delhi quartzite (from outcrops 75 to 125 km directly north of the northern Rajasthan steatite sources) was being used during Period 3C (Figure 5.13). These results for steatite artifacts could constitute an additional piece of evidence indicating that, of all residents at Harappa, people in this part of the site had slightly stronger trade relations with groups in the eastern part of the Greater Indus region.

Overall, however, I would characterize the synchronic patterns of steatite acquisition at Harappa as being similar to those evident for chert during the site's urban phases. For the most part, everyone had access to and was mainly using raw material acquired from the same broad source area (the "northern" region for steatite and the Rohri Hills for chert). Within that region, multiple deposits were being exploited but one zone or deposit in particular (the Sherwan zone for steatite and the Rohri town deposit for chert) seems to have been the source for the majority of the stone used. Raw materials from other source regions (northern Rajasthan for steatite and the Mohmand Agency for chert) may have sometimes acquired, but only infrequently and/or in very minor amounts.

***Unfired steatite artifacts from other sites***

In this sub-section, the unfired steatite artifacts from Mohenjo-daro, Mehrgarh, Nausharo, the "unknown" Loralai site, Gola Dhoro, Nagwada, Mitathal and Tepe Hissar are examined. Before focusing on the CDA results for each site individually, I present and discuss a CA performed on 177 of the steatite artifacts (the entire set excepting the Mitathal seal and seal boss from Harappa). This was conducted in order to first get a clear understanding of how compositionally similar or dissimilar the steatite artifacts from the other sites examined were to the kinds of raw materials that were being used at Harappa. The CA dendrogram in Figure 7.46 was generated using the same complete linkage method that was employed to make the others in this chapter and its appendices. On it, the branches representing artifacts from the seven sites are noted using their two or three letter site codes (a key is provided on the figure). The branches representing artifacts from Harappa were left blank (it was too busy with artifact numbers). The specific numbers for all of the artifacts are found in the full size reproduction of the dendrogram (Appendix 7.11 sections A through D). Preceding the number for most of the artifacts from Harappa in Appendix 7.11 is one of four short codes in parentheses – "(C1)" through "(C4)." These codes denote the numbered cluster each one was originally a member of in the CA of just 140 artifacts from Harappa (Figure 7.21).

The 177 artifacts form two main clusters that split at RDCC 25. I first briefly discuss the distribution of the Harappan artifacts. The larger main cluster (to the left of the split) contains most of the artifacts from Harappa that had been in clusters C1 through C4 on Figure 7.40. The smaller main cluster (right) contains two former C4 artifacts as well as three had been outlier not assigned to clusters. Within the largest main cluster the Harappan artifacts group in much the same way as they did in Figure 7.40. The one difference is that around half of those that had been

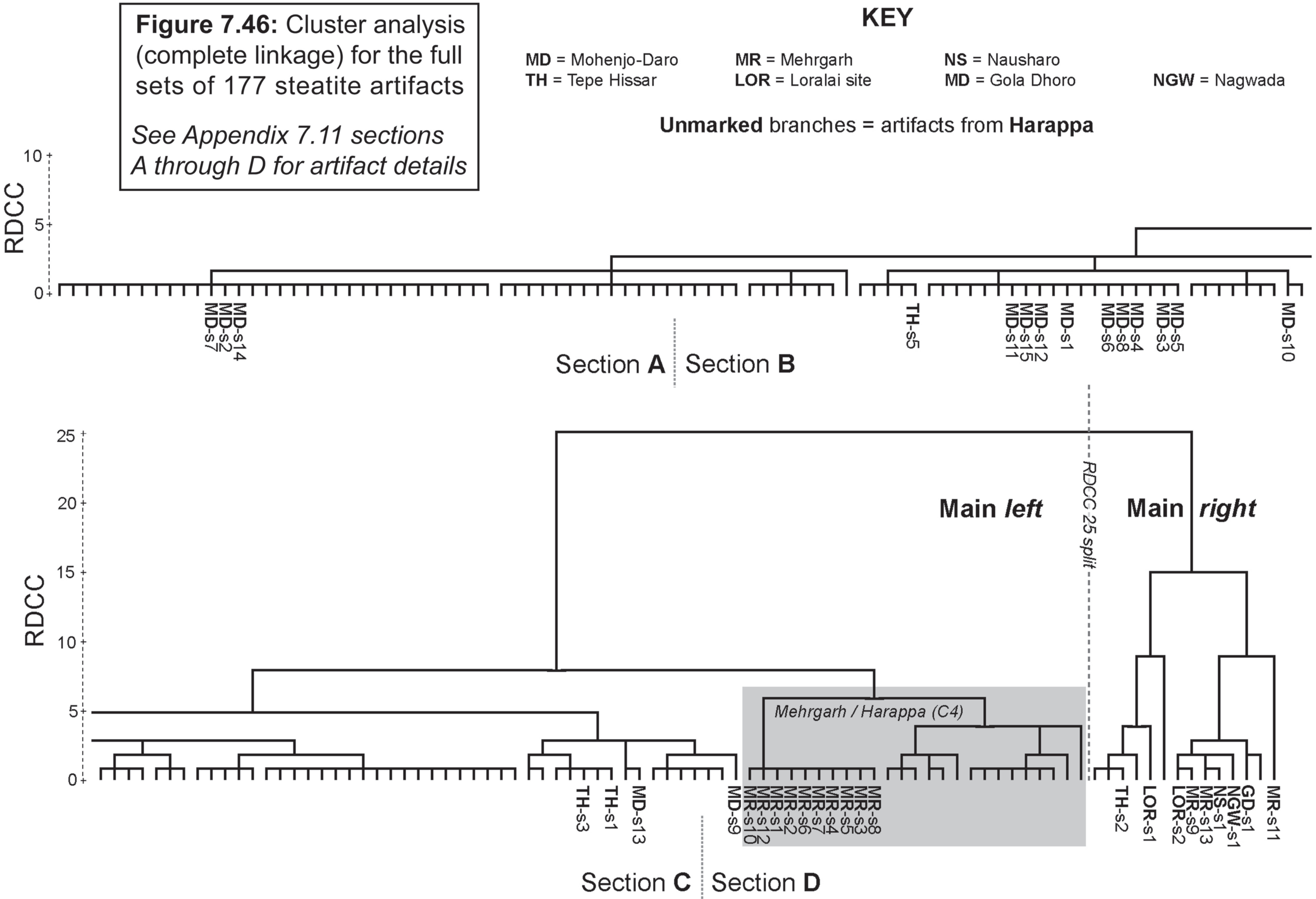



**Figure 7.46:** Cluster analysis (complete linkage) for the full sets of 177 steatite artifacts

*See Appendix 7.11 sections A through D for artifact details*

originally been designated as C3 now appear with C1 artifacts while the other half still form a distinct sub-cluster of their own.

The manner in which the artifacts from the seven other prehistoric sites fall on the dendrogram is both interesting and informative. Compositionally, the 15 fragments from Mohenjo-daro (MD) are closely related to those from Harappa, which suggests that they may be from the same source or sources. Ten of the 13 artifacts from Mehrgarh (MR) group together in a very closely related (RDCC 1) sub-cluster that, within the larger main cluster, is set well apart from the Harappan artifacts. At RDCC 6, it joins another sub-cluster made up of Harappan artifacts, most of which had been in C4 on Figure 7.40. This Mehrgarh/Harappa-C4 sub-cluster is itself distinct from the other artifacts from Harappa (and Mohenjo-daro) in the larger main cluster. All of the Harappa-C4 artifacts have been predicted by CDA to belong to one of the Sherwan zone sources. However, their comparatively close association with the Mehrgarh artifacts raises the possibility that they *may* have actually been derived from a related deposit nearer to that site in Balochistan.

The majority of the remaining artifacts from the other sites are all members of the smaller main cluster on the right side of the RDCC 25 split. These appear to be composed of kinds of steatite that are very different from most of that used at Harappa. The exceptions are three of the four fragments from Tepe Hissar, which of all the artifacts in the archaeological set, seem to be compositionally most closely related to those from Harappa.

Informed by the results of the above CA, the artifacts from each of the seven other prehistoric sites are now examined using CDA. The parent-rock association of each artifact was determined in the CDA of the archaeological set and full geologic set (Figure 7.32). Most of the PGMs discussed in the sub-sections below were generated during either the ultramafic parent-rock (Figure 7.34) or the dolomitic parent-rock (Figure 7.35) CDA. In a few instances select artifacts are compared to refined or selected subsets of samples.

*- Mohenjo-daro*

Indus craftspeople working in both the DK-A and Moneer areas at Mohenjo-daro would appear to have been involved in the very same steatite acquisition networks as were their counterparts at Harappa. The first PGMs for nine of the 15 unfired steatite artifacts (Figure 7.7 A) analyzed from the site (listed in the second column of Appendix 7.5) are "northern" region sources – six are assigned to one of the Sherwan zone deposits and three are predicted to belong to the Daradar (PD), Kurram Agency source. Three of the remaining six artifacts have second PGMs in the Sherwan zone and so could be compositional outliers that came from that source. However, the first PGMs for five of those six is in a northern Rajasthan deposit (either ANB or ATM). One final artifact has a first PGM in a southern Rajasthan deposit (RDP) but it has a second PGM in a northern Rajasthan one (ANB) and, thus, may very well be a compositional outlier from the latter source area. The close compositional similarities exhibited by steatite artifacts from Mohenjo-daro and Harappa on the CA dendrogram (Figure 7.46 and Appendix 7.11) enables me to argue with a good deal of confident that those artifacts from both sites having the same PGMs are very likely from the same geologic sources. Later, I discuss artifacts from Mehrgarh that have also been assigned these same PGMs but which are quite clearly compositionally distinct from the Harappa and Mohenjo-daro artifacts.

Although the sample of artifacts from Mohenjo-daro is roughly one-tenth the size of that from Harappa, it nonetheless has permitted some interesting similarities and differences in steatite acquisition patterns between sites to be observed. To begin with, like at Harappa, the majority of steatite used at Mohenjo-daro seems to come from sources

in the "northern" region and the majority of that majority is from the Sherwan zone of the Hazara District. However, whereas only around 5% to 10% (at the very most) of the analyzed artifacts at Harappa genuinely appear to have come from sources other than those in the north, up to 40% of the artifacts from Mohenjo-daro were likely acquired from deposits located in northern Rajasthan. Interestingly, this acquisition pattern for Mohenjo-daro much more resembles that of just Mound F at Harappa than it does of that entire site.

Also like at Harappa, it appears as if craftspeople working in different parts of Mohenjo-daro had access to the same sources of steatite. Artifacts assigned to the Sherwan zone, Kurram Agency and Alwar District deposits are found in both the Moneer and DK-A areas. Examples of steatite from two other source areas accessed by residents of Harappa – the Khyber Agency and Jammu, were not identified among the Mohenjo-daro artifacts. With regard to Jammu, the use of stone from the deposit analyzed in that region (JAMPT) seems to have ceased after Period 3B at Harappa. This could account for its absence on the surface of Mohenjo-daro, which is roughly equivalent to Period 3C. However, the absence of Khyber Agency and Jammu steatite may simply be due to the low sample size. On that note, it is important to recognize that the patterns of source usage suggested by the mere 15 samples from Mohenjo-daro could change dramatically when additional steatite artifacts are analyzed. The ones discussed here, thus, should be considered provisional.

The analysis of the Mohenjo-daro fragments has, nonetheless, generated new insights into Indus Civilization steatite acquisition networks as well as new questions about them. At this point it appears that residents of Mohenjo-daro did not acquire steatite from any of the three potential source areas nearest to their city (southern Balochistan, northern Balochistan or southern Rajasthan/Gujarat). One sample (MD-s13) did have a first PGM in southern Rajasthan's Deola (RDP) deposit but, like those artifacts assigned to this region at Harappa, I believe it to be a misclassified outlier. The results instead indicate that the majority of the Mohenjo-daro artifacts analyzed probably came from sources 800 to 900 km to northeast of the city in northern Pakistan while a large minority came from sources around 800 km due west in northern Rajasthan. That the steatite acquisition networks city residents were involved in could be that far-reaching is not at all surprising. Throughout this book I show that raw materials such as chert (Chapter 6), agate (Chapter 8), limestone (Chapter 11) and lead (Chapter 12) were being transported, sometimes in bulk sizes, over equal or greater distances from the southern part of the Greater Indus region to the northern part. The Mohenjo-daro steatite artifacts constitute new evidence that an important variety of raw material was being moved, probably via the same trade networks, from the north and northeastern parts of the Greater Indus region toward the south.

These results, however, raise the question – Why did craftspeople at Mohenjo-daro (or their suppliers) not exploit much closer sources of seemingly good quality steatite, most especially the very nearest ones in Balochistan that were in the general vicinity of Indus Civilization settlements? In the case of the Wayaro sources of southern Balochistan it could just be an issue of timing and artifact recovery. Ute Franke and others report (2000: 199) that the Harappan occupation of Bakkar Buthi (the site nearest the Wayaro deposits) ended sometime prior to what is equivalent to Period 3C at Harappa – or the "Late Phase" at Mohenjo-daro. This fits well with the evidence at Harappa itself, which indicates some Wayaro steatite was brought to that site during Period 3A but not thereafter. If raw material from the same source was likewise acquired by residents of Mohenjo-daro only at that time then any remnants of it probably lay deeply buried beneath the city's "Late Phase" surface levels. But the question then would be

– Why did Indus Civilization peoples (at Mohenjo-daro and Harappa) not continue to use steatite from southern Balochistan? Even if Harappans quit that region in the latter part of the urban period and, consequently, did not have had direct access to its steatite resources they likely could have still obtained the stone indirectly through interaction with the highland Kulli peoples dwelling there. I have concluded (and will argue in the final section of this chapter) that the reason why steatite from the Wayaro area and the other source regions closer to Mohenjo-daro were apparently not used by craftspeople at that site was probably because when it was heat-treated it did not transform into the white color they desired.

*- Mitathal*

Although a surface find, the small rectangular seal fragment from the site of Mitathal (Prabhakar 2010) almost certainly dates to the latter part of the Harappan Phase (ca. 2200 to 1900 BC or Period 3C at Harappa). In the CDA of the archaeological and full geologic set (Figure 7.32), the seal was assigned a first PGM in the dolomitic steatite deposit at Gandra, Panchmahal District, Gujarat and a second PGM in the Nangalhari-Bairaswas of the Alwar District, northern Rajasthan. In this instance, it was decided to assign provenience to the artifact based on its second PGM. Several factors led to this decision. To begin with, Gandra is 725 km south of Mitathal as the crow flies. While it is clear that Harappans transported steatite over even longer distances, a PGM in this particular deposit still seems anomalous. No other artifact examined in this study was predicted to come from Gandra, not even those from sites the same region at it such as Gola Dhoro, Nagwada or, as recent but still unpublished analyses shows, Dholavira. On the other hand, the deposit at Nangalhari-Bairaswas and related ones in the Alwar District are among the closest sources to the site of Mitathal and, most significantly, steatite from northern Rajasthan seem to also have been used, if only to a limited degree, at the cities of Harappa and Mohenjo-Daro.

*- Mehrgarh and Nausharo*

Although the 13 steatite artifacts from Mehrgarh (Figure 7.7 B) date to before the foundation of Harappa, their analysis has informed the current study by providing valuable glimpses of unsampled raw material sources that are probably located somewhere in the Balochistan and/or Afghanistan regions. One of those sources is represented by 10 of the 13 artifacts, which together form the closely related and highly distinct sub-cluster highlighted on Figure 7.46. Admittedly, I am making an assumption that all ten artifacts are from the same deposit. They could be from ten different deposits in ten different geologic formations that just happen to be highly similar to one another compositionally. I very much doubt that is the case, however. The same ten artifacts comprise a single, equally related and distinct sub-cluster (see Appendix 7.9 section G) on the dendrogram of the archaeological and full geologic sets (Figure 7.36). All are dolomitic in origin (as indicated by the initial CDA – Figure 7.32), are black or dark grey in color and the majority (7 of 10) were found together in the MR4 area atelier that dates to the site's early Chalcolithic Period (Mehrgarh IIB) (Jarrige 1981: 99). Although in the dolomitic parent-rock CDA (Figure 7.35) all were assigned to one of the northern Rajasthan deposits (ANB, ATM or JJK), the actual location of the source is probably not in that region 800 to 900 km to the east-southeast of Mehrgarh. Instead, it is likely somewhere closer to the site in Balochistan or Afghanistan. The Muslimbagh and Las Bela ophiolites can be ruled out as potential sources as the artifacts are composed of dolomitic steatite. In all likelihood, the Neolithic and early Chalcolithic craftspeople at Mehrgarh who used this stone acquired it from an occurrence in central Balochistan such as the one reported (Tariq *et al.* 1998: 16) in Shirinab Formation shales at Chuttok in the Kalat District, which is just 90 km west of the site.

This can only be confirmed, however, after samples from that and related occurrences in the region are collected, analyzed and compared to the Mehrgarh artifacts.

It would appear that the "source" suggested by the ten Mehrgarh artifacts, wherever it is actually located, was used for at least two millennia. Three of the ten artifacts (MR-s8, MR-s10 and MR-s12) were recovered from the site's Period I levels (ca. 7000 to 5500 BC) and the remaining seven (MR-s1 through MR-s7) date to Period IIB (ca. 5000 BC). Artifacts from the site's later periods will eventually need to be analyzed in order determine if the "source" continued to be used after that. As it now stands, there is no evidence that it was. The single bead from nearby Nausharo, which I discuss shortly, is ultramafic in origin and so cannot be from the same "source." Although many of the 15 dolomitic steatite artifacts from Mohenjo-daro have the same PGMs as the ten from Mehrgarh, on the CA dendrograms (appendices 7.9 and 7.11) they are clearly very different from them compositionally. The artifacts from Harappa with those PGMs likewise appear very different on the dendrograms. On Figure 7.46, I highlighted a sub-cluster of Harappan artifacts that joins the Mehrgarh sub-cluster at RDCC 6. Those artifacts were assigned to the Sherwan zone and I drew attention to them in order show how they may actually be from a different source, *perhaps* in Balochistan, due to their comparatively (in relation to other artifacts from Harappa) close association with the Mehrgarh sub-cluster. I do not, however, believe that they are from the same "source" as the ten Mehrgarh artifacts.

Experimental studies conducted by Barthélémy de Saizieu and Bouquillon (1997: 64) and by myself (Appendix 7.12) have shown that black steatite from Mehrgarh becomes pure white when heated to a sufficient temperature. It is somewhat of a mystery then why the proposed "source" was not exploited by Indus Civilization peoples as this was evidently one of the properties they desired. It might be that the deposit itself was exhausted of good material prior to the Harappan period. Or, perhaps, Indus peoples simply did not have access to the source area, wherever that might have been. Maybe the situation was like that of chert. That is, perhaps one (or just a few) high-quality type of steatite from an extensive source area was used to the almost total exclusion of raw material from minor sources.

The three remaining artifacts from Mehrgarh are each beads or bead fragments from the site's Period I levels. In the first CDA (Figure 7.32), both MR-s9 (composed of a red steatite) and MR-s13 (made from a black steatite) were assigned to ultramafic deposits – DMB and LBW1 respectively. In the second, ultramafic parent-rock only CDA (Figure 7.34) their first PGMs respectively shifted to RSB and ZTT. In short, MR-s9 appears more closely related to samples from ultramafic deposits in the southern Rajasthan/Gujarat region while MR-s13 is much more like steatite from the ophiolites of Balochistan. However, with regard to MR-s9, I argue (below) that it is probably actually from a source in a region to the west of the Indus Valley. When it and MR-s13 are compared to a geologic set made up of only the Balochistan sources (Figure 7.47), they are both assigned to deposits in the Muslimbagh ophiolite (MR-s9 to ZTT and MR-s13 to ZTAK).

Artifact MR-s11 (made from a pale green steatite) is somewhat unusual. Although in the initial CDA it was assigned, like the first ten Mehrgarh artifacts, to a dolomitic northern Rajasthan deposit (JJG), its higher than normal concentrations of certain metallic elements sets it apart from those and all other dolomitic artifacts in the archaeological set. Note its distinct positions on the scatterplots (figures 7.32 and 7.34) and dendrograms (appendices 7.9 and 7.11). Although it was not assigned a first (or second) PGM in one of the Muslimbagh ophiolite sources, on the initial CDA scatterplot (Figure 7.32) it falls among the Urgasai Nasir deposit (ZUN) samples, which was one of the ultramafic sources that overlapped

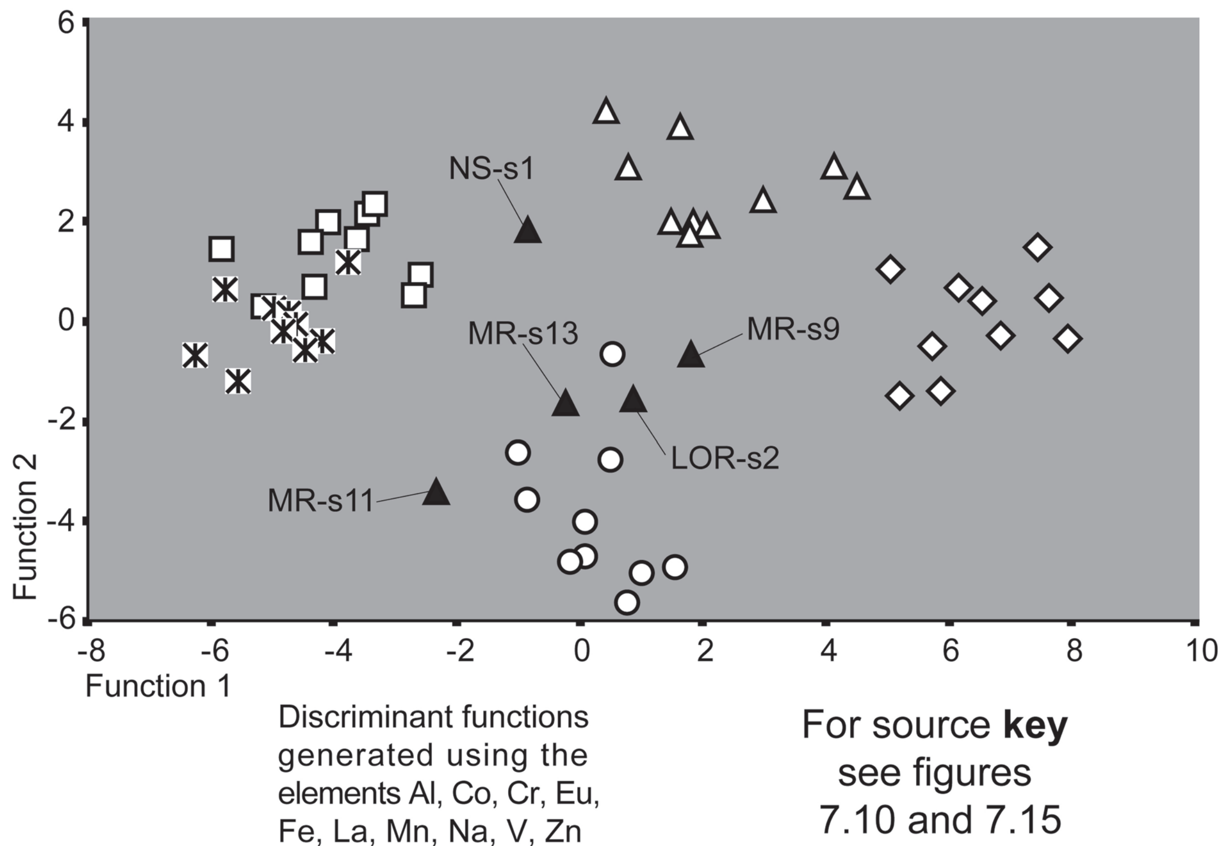



**Figure 7.47** Steatite artifacts from Mehrgarh, Nausharo and Loralai compared to ultramafic steatite sources in Balochistan.

the dolomitic ones. Recall that I speculated that this overlap might reflect the deposit's possible formation in a contact zone between magnesium-rich sedimentary rock and the ultramafic rock of the ophiolite. This may have resulted in dolomitic-like steatite bodies with higher than normal concentrations of metallic elements (or vice-versa). Artifact MR-s11, although perhaps not from ZUN, may be from this type of an occurrence. When it is compared to the geologic set made up of only the Balochistan sources (Figure 7.47), it is assigned to the Takhahen (ZTAK) deposit in the Muslimbagh ophiolite.

The broken red steatite bead (NS-s1) from Period III (ca. Period 3B at Harappa) levels at Nausharo clearly appears to be from a source in southern Balochistan. In both the initial (Figure 7.32) and ultramafic parent-rock CDA (Figure 7.34), it was assigned first and second PGMs in one of the Wayaro area deposits (LBW1 or LBW2). It was likewise assigned to that region (LBW2) in the CDA using the refined set of samples from the five Balochistan sources only (Figure 7.47). However, on that scatterplot it falls somewhat away from the Wayaro datapoints suggesting that, although it still most closely resembles steatite from this source, it may not have been obtained from one of those exact deposits. This is not surprising as the geologic samples it is being compared to were collected from modern steatite mines. The raw material for the bead likely came from one of the many old workings and exhausted shear zones (noted above) in the Wayaro area.

The Nausharo bead is one of the very few Harappan period artifacts analyzed in this chapter that is composed of steatite from an ultramafic source. The only others are the fragment (H97-7784-27) from Period 3A at Harappa and two artifacts from Harappan sites in Gujarat (which I discuss shortly). The Nausharo bead and the Harappa fragment are

the only ones from the Wayaro source. The bead's Nausharo III / Harappa 3B date means that the raw material could have been acquired via interaction with Indus Civilization peoples who at that time still occupied the settlement of Bakkar Buthi (Franke-Vogt *et al*. 2000: 199), which is less than 20 km from the source. Later, I argue that Wayaro steatite, although apparently accessible, was not widely used during the Harappan period because it does not fire to a white color. The Wayaro/Shah Noorani-like steatite bead (Figure 7.14 C) that I observed in the Balakot collection was probably finished and not meant to be fired. The thick-walled style of the Nausharo bead (Figure 7.7 B bottom row, far right) suggests that it might not have been intended for heat-treatment either.

In the end, it is possible to state with a good degree of confidence that one of the beads (MR-s13) from Period 1 at Mehrgarh is made of steatite from a source in the Muslimbagh ophiolite of northern Balochistan, while the bead from Period III at Nausharo is composed of steatite obtained from a deposit in the Las Bela ophiolite of southern Balochistan. The remaining Mehrgarh artifacts (MR-s9, MR-s11 and the ten representing the unknown "source") *could* genuinely be from the deposits in Rajasthan or Gujarat that they were assigned to in the initial CDAs. However, given what is currently understood of the early cultural sequence at Mehrgarh (Jarrige *et al*. 2005), I would argue it is far more probable that their actual sources are located to the west of the Indus Valley rather than to the east of it. The recovery of lapis lazuli and marine shell beads in periods I and II levels (Barthélémy de Saizieu 2003: tables 9 and 12) indicates that the interaction networks site residents then participated in stretched northward to Afghanistan and southward to the Arabian Sea. Some of the unsampled sources across that broad area (I have already noted possibilities in eastern Afghanistan) may compositionally resemble those of the Aravalli Range and, thus, steatite from them could have been misassigned to sources in Rajasthan and northern Gujarat. The ten fragments representing the black steatite "source," in all likelihood come from known but unsampled dolomitic occurrences in central Balochistan. Beads MR-s9 and MR-s11 *may* both be from a deposit in the Muslimbaugh ophiolite. If not, then they are still most likely from a source located in Balochistan or Afghanistan.

*- "Unknown" Loralai site*

Although without secure proveniences, the analysis of the sawn fragment and black beads (Figure 7.7 C and D) attributed to an "unknown" site in the Loralai district have provided an informative glimpse of prehistoric steatite usage in northern Balochistan.

In both the initial (Figure 7.32) and dolomitic parent-rock CDAs (Figure 7.35), the sawn red steatite fragment (LOR-s1) was assigned first and second PGMs in one of the Sherwan deposits (SC or SKK). However, although clearly of dolomitic origin, the fragment is compositionally quite different from most of the other dolomitic artifacts in the archaeological set, the majority of which were assigned to the Sherwan zone. Note its position apart from the main body of steatite artifacts on Figure 7.35 (it is identified on the figure using a red "+") as well as on the dendrogram of the 177 archeological samples (Figure 7.46 and Appendix 7.11). Rather than being from the Sherwan zone, it is more likely that the artifact is either from an unreported dolomitic source in northern Balochistan or, perhaps, one of the unsampled potential sources I noted (above) in eastern Afghanistan.

The black beads are composed of an ultramafic steatite that quite clearly appears to be from a source in the Muslimbagh ophiolite of the northern Zhob District, which is approximately 100 km to the northwest of the Loralai Valley. In both the initial (Figure 7.32) and ultramafic parent-rock CDAs (Figure 7.34), the bead analyzed was assigned a first

PGM in the Tor Tangi deposit (ZTT). It was assigned to the Takhahen deposit (ZTAK) when compared to the five sampled sources in Balochistan alone (Figure 7.28).

Unlike the ten black steatite artifacts from Mehrgarh that are from the unidentified dolomitic "source," steatite from the ultramafic Muslimbagh ophiolite will not become white when heated (unless it is already white to begin with – and then it turns a dull white). I have confirmed this through heating experiments involving geologic samples from that source formation (Appendix 7.16) as well as one involving the black beads from the "unknown" Loralai site. In the latter, I heated a single bead in a muffle furnace for one hour at 1200°C. That time and temperature is more than sufficient to turn any steatite white *if it is predisposed to do so* (see appendices 7.12 and 7.16). The bead became a dull reddish-gray color when heat-treated in this way. That, however, was likely not an issue for the craftspeople who fashioned the Loralai beads from Muslimbagh steatite as they probably intended them to remain black. Harappan craftspeople, on the other hand, would not have desired raw material with this property. This is very likely one of the main reasons why steatite from the Muslimbagh deposits, despite being in the same general region as a very large Indus Civilization settlement like Dabar Kot, has not been identified among the Harappan period artifacts examined in this chapter.

*- Nagwada and Gola Dhoro*

The INAA results for the fragment from Nagwada and the broken unicorn seal from Gola Dhoro (figures 7.7 E & F) indicate that Harappans at those sites were involved in steatite acquisition networks that were very different from those of their contemporaries at Harappa and Mohenjo-daro. On the scatterplot from the CDA of the archaeological and full geologic sets (Figure 7.32), both artifacts fall squarely among the large cluster of geologic samples from ultramafic sources. This alone sets them apart from 99% of the steatite artifacts analyzed from Harappa and all of those analyzed from Mohenjo-daro.

The Nagwada fragment (NGW-s1) is most closely related to steatite occurring in ultramafic deposits located in the northern Gujarat / southern Rajasthan region. In both the initial (Figure 7.32) and ultramafic parent-rock CDAs (Figure 7.34), the fragment was assigned a first PGM in the Shiv Bola (RSB) mine of the Udaipur District, Rajasthan and a second PGM in the Dev Mori-Kundol occurrence (DMK) in the Sarbarkantha District, Gujarat. Both deposits are part of the Rakhabdev Ultramafic Suite of the southern Aravalli Range and when the fragment is compared to samples just from the occurrences in that formation (Figure 7.48) it is assigned a first PGM of DMK. That occurrence is the closest source to the Nagwada. Harappans living at that site might have acquired the steatite by making the 175 km journey east across the North Gujarat Plain themselves or, perhaps, through interaction with the hunter-gatherer populations of that region (Possehl 1980: 73).

The precise source of the steatite used to carve the unicorn seal from Gola Dhoro is somewhat more difficult to pin down. In the initial CDA of the archaeological and full geologic sets (Figure 7.32) it was assigned a first PGM in the Sakhakot-Qila ophiolite deposit (KOT) of the Mohmand Agency. In the CDA involving just ultramafic deposits (Figure 7.34), it was again assigned a first PGM of KOT and it was given a second PGM of CHT, which is the source code for samples collected from the Drosh ophiolite near Tar village in the Chitral District. In spite of these consistent assignments to the ultramafic deposits in the ophiolites of northern Pakistan, I consider it most unlikely that the steatite used to carve the seal was actually derived from that region. My doubts on this matter do not stem from the great distance that exists between Gola Dhoro and the KOT and CHT deposits (around 1250 and 1400 km

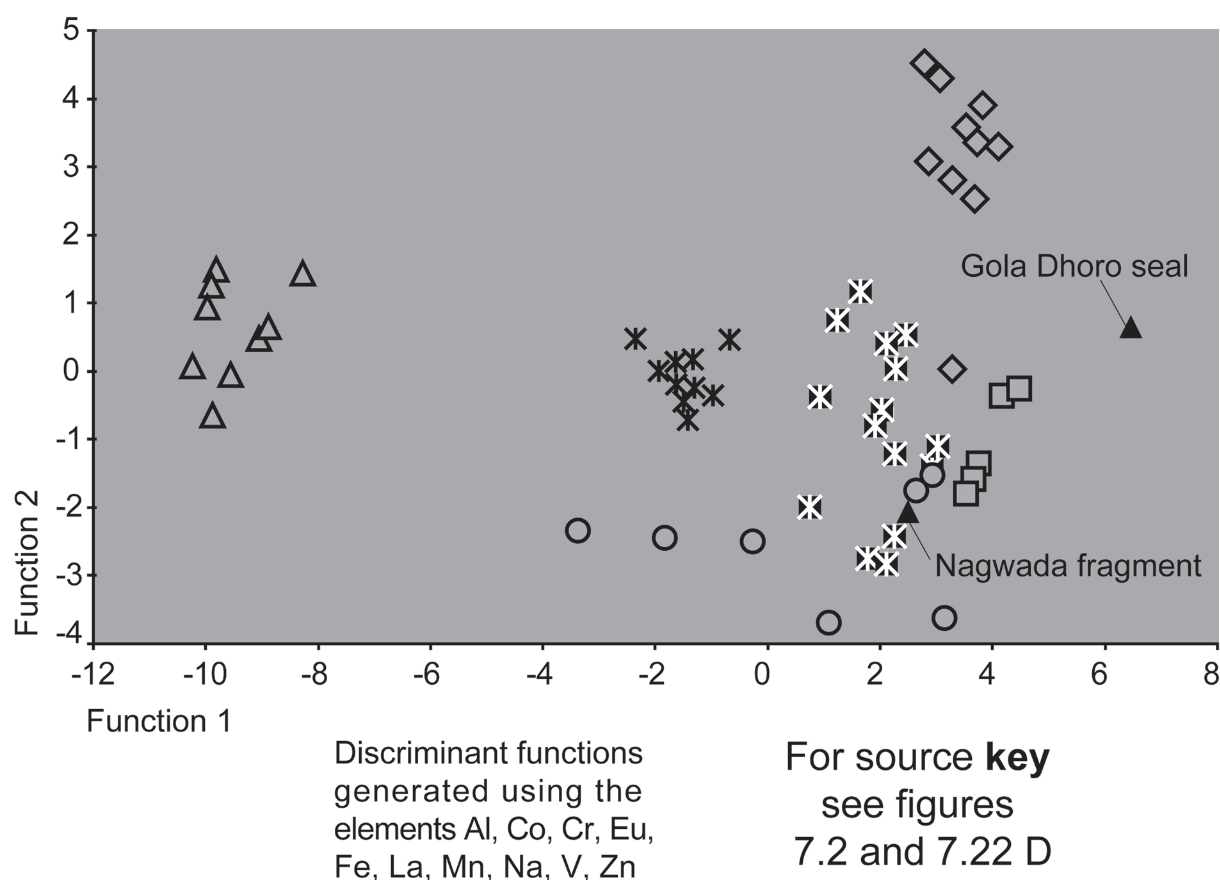



**Figure 7.48** Steatite artifacts from Nagwada and Gola Dhoro compared to ultramafic steatite sources in southern Rajasthan and northern Gujarat.

respectively). Beads made of lapis lazuli – a stone that originates even farther away (≈ 1475 km) in northern Afghanistan, have been recovered at the site (IAR 1996-97: 25). Rather, I base my reservations on what we are now beginning to understand of steatite use and acquisition at Indus Civilization settlements located between northern Pakistan and the Gujarat region. The seal could have been manufactured at a settlement that was comparatively closer to the KOT and CHT deposits, such as Harappa or Mohenjo-daro, and then discarded by a trader or some other person visiting or returning to Gola Dhoro. However, the results of this study suggest that it is not likely to have been made at either of those cities as craftspeople at them seldom (if ever) used any ultramafic steatite, much less any from those particular sources in northern Pakistan. The seal could have also been made at a Harappan settlement in Gujarat using raw material obtained from the distant KOT or CHT deposits. But if this was the case then the evidence would indicate that the acquisition/trade networks for that kind of steatite, which presumably would have gone through the Indus Valley, bypassed the major Indus urban centers. I consider that to be an unlikely possibility. Admittedly, however, the low sample sizes from those cities (particularly Mohenjo-daro) means that examples of ultramafic steatite artifacts from northern Pakistan sources may have simply missed being detected.

In all likelihood the Gola Dhoro seal was manufactured in Gujarat using ultramafic steatite from a deposit located somewhere other than northern Pakistan. The artifact's compositional similarity to samples from the Sakhakot-Qila and Drosh ophiolites suggests that the actual raw material source *might* be found in the same type of geologic formation. The Las Bela ophiolite of southern Balochistan is the nearest such formation but, as I have already

noted several times and will discuss further in the next section, steatite from deposits occurring in it evidently does not become white when heated. Thus, the white Gola Dhoro seal is probably not composed of raw material derived from that formation. The Semail ophiolite of Oman (not shown on Figure 7.2), although located 1200 km to the west across the Arabian Sea, should be considered a potential source because of the clear evidence for the existence of maritime interaction networks between Eastern Arabia and the Gujarat region during the Harappan Period (Chakrabarti 1998; Edens 1993; Possehl 1997a; Rao 1979b). However, until samples from deposits in that formation are collected and analyzed, it is impossible to do more than speculate as to whether or not steatite was among the raw materials that may have been exchanged through those networks.

In the end, it is most probable that steatite used to make the Gola Dhoro seal came from one of the ultramafic deposits nearest to the site itself. In the initial CDA of the full archaeological and geologic sets (Figure 7.32), the second PGM of the seal was the Dev Mori-Kundol occurrence (DMK) in the Sarbarkantha District of northern Gujarat. If the KOT and CHT deposits are removed from the full geologic dataset and another CDA is performed (not shown) then DMK becomes the artifact's first PGM. When the seal is compared to just the sampled ultramafic deposits of southern Rajasthan and northern Gujarat (Figure 7.48), it is assigned a first PGM in the Rishab-der deposit (RRD) of the Udaipur District and a second PGM of DMK. Note that on the scatterplot for that CDA the artifact plots away from the clusters representing those deposits. This suggests that it is perhaps not from either one of those exact sources, which not surprising as they are modern mines. It could still very well be from a related deposit in the same geologic formation, however. There are a half-dozen reported occurrences around the Dev Mori area (Chatteerjee 1964: 436) in addition to the two sampled for this study (DMK and DMB). Moreover, scores of other sources might have been accessible to Harappans (or their suppliers) elsewhere in the Rakhabdev Ultramafic Suite, which continues northward from Gujarat into steatite-rich southern Rajasthan (Gupta *et al*. 1997). It is hoped that an expanded program of sampling across that formation will one day permit a more geographically accurate identification of the source of the steatite used to make the seal.

*- Tepe Hissar*

When the four pieces of sawn steatite from the site of Tepe Hissar (Figure 7.7 G) in northern Iran are compared to all 37 deposits in the geologic dataset (Figure 7.32), each is predicted to belong to a dolomitic source located in Rajasthan (TH-S1 and TH-S3 = RSA, TH-S2 and TH-S5 = ATM). The results were the same when the fragments were compared to samples from just the 23 dolomitic deposits in the dataset (Figure 7.35). On the CA dendrogram of the 177 archeological samples (Figure 7.46), one of the fragments (TH-s2) groups apart in a small distinct cluster to the right of the RDCC 25 split but the rest are very similar compositionally to artifacts from Harappa and Mohenjo-daro. Had the four fragments been recovered at one of those sites instead of in Iran then there would be little reason to argue that they were derived from a source area other than the one that they were predicted belong to by CDA. However, because of the artifacts' archaeological provenience their PGM assignments must be regarded cautiously.

It is not impossible that the four Tepe Hissar fragments are genuinely composed of steatite that was extracted from deposits in Rajasthan and then transported over 2200 km to consumers in northern Iran. Raw materials and/or finished items were sometimes moved tremendous distances across late Bronze Age southern and western Asia (Ratnagar 2004). This fact is best exemplified by the distribution of lapis lazuli artifacts at sites from

Egypt to the Indian Subcontinent (Casanova 1997; Herrmann 1968; Tosi 1974; von Rosen 1990). The unmistakably Harappan-style "etched" (bleached) carnelian beads recovered in Tepe Hissar IIIC levels (ca. late 3rd / early 2nd millennium BC) and at several other late Bronze Age sites in Iran (Heskel 1984: 341) demonstrate that some material goods made it to that distant region from South Asia during the Harappan Period. However, there was only one viable source of lapis lazuli in this part of the ancient world (see Appendix 4.4) and the Harappans were the only ones who were creating "etched" carnelian beads at that time. There were no other sources available to consumers in ancient Iran (or elsewhere) who wished to posses such items. Steatite, in comparison, would have been widely available. Although I will shortly argue that raw material from certain deposits was, depending on what was being manufactured, preferred over that from other deposits, there is no reason at this point to believe that those preferable types only occurred in South Asia. If we presume that the Tepe Hissar steatite was from a source closer to that site in Iran or Afghanistan then it would indicate that there are dolomitic deposits in those regions to the west of the Indus Valley that are compositionally similar the ones in Rajasthan. This possibility allows the PGMs of some of the artifacts analyzed from other sites to be considered in a new light.

I previously argued that artifacts from Mehrgarh assigned to steatite deposits in Rajasthan were very likely to have been, in actuality, derived from a source or source area located to the west of the Indus Valley in central Balochistan or, perhaps, in Afghanistan. Although the Tepe Hissar fragments do not appear to be from the same source(s) as those particular artifacts (observe their dissimilarly on the CA dendrogram of Figure 7.46), they do, as already noted, closely resemble some of the ones from Harappa and Mohenjo-daro. Respectively, around 5% and 40% of the artifacts analyzed from those two cities were predicted to belong to steatite deposits in Rajasthan. One may ask – If the PGMs assigned to the Tepe Hissar fragments are questionable, then might those artifacts from Harappa and Mohenjo-daro that are likewise predicted to belong to sources in Rajasthan potentially be misclassified? And if so, then is it possible that the steatite such artifacts are composed of instead came from the same source or source area as the compositionally similar Tepe Hissar fragments? The answer to both questions is – most definitely yes, it is *possible*.

The evidence provided by the Tepe Hissar artifacts, although indirect and limited, suggests that occurrences of dolomitic steatite that are compositionally analogous to those in Rajasthan may exist in regions to the west of the Indus Valley. This means that artifacts from Harappa and Mohenjo-daro that were assigned PGMs in Rajasthan deposits could *possibly* instead be from occurrences in Afghanistan or, perhaps, even Iran. However, this possibility cannot be tested until samples from dolomitic sources in the latter two regions are obtained, analyzed and compared to the artifacts from those sites. Therefore, for now, the northern Rajasthan provenience assignments made for certain artifacts from Harappa and Mohenjo-daro will stand and be used to designate a regional point of origin in the upcoming summary of Indus tradition steatite acquisition networks (Figure 7.49). Nevertheless, it should be recognized that although all provenience determinations made in this chapter are provisional, the PGMs for those artifacts are perhaps the most liable to change when samples western regions are eventually incorporated into the geologic dataset.

*- Addendum: Recent findings from Dholavira and Rakhigarhi*

Data from the analysis of steatite artifacts excavated at the Indus cities of Rakhigarhi in Haryana and Dholavira in Gujarat were received as this book was being prepared for publication. Although these data have not yet been fully evaluated, my initial




**Figure 7.49** Indus Tradition steatite acquisition networks (provisional)

impressions of the results are briefly stated here.

All of the artifacts analyzed from Rakhigarhi and over two-thirds of those from Dholavira are composed of dolomitic steatite that appears to originate from the very same "northern" sources preferred overwhelmingly residents of Harappa and Mohenjo-Daro. Most of the remaining artifacts from Dholavira seem to be made from steatite derived from either the Dev Mori source in eastern Gujarat or geologically related deposits just across the border in southern Rajasthan.

## SUMMARY AND DISCUSSION

Steatite occurs in every major highland region surrounding the Indus Basin. Yet the provenience composition of the raw steatite assemblage at Harappa is far less variable, both synchronically and diachronically, than might be expected given the evidently high demand for this variety of rock and the geographical wide distribution of potential sources. For the better part of two millennia, residents of Harappa acquired most of the raw material they used from only a handful dolomitic sources located in the northern part of present-day Pakistan and India. In this final section, I first review the various steatite acquisition networks that were identified in this chapter. I then discuss the heat-treatment of steatite by Indus Tradition peoples and their need for raw material that would become white when it was fired. I argue that this need is probably the main reason behind the sustained use by Harappans of one type of steatite from a single, albeit broad, source region.

Figure 7.49 depicts the Indus Tradition steatite acquisition networks provisionally defined in this chapter. Each are indicated using a line with an arrow on its terminal end. Green lines are networks for dolomitic steatite and black lines are networks for ultramafic steatite. The routes from the sources to the sites are entirely conjectural. Variations in line thickness for networks to Harappa, Mohenjo-daro and Mehrgarh are meant to approximate the overall assemblage provenience compositions for those sites. For example, the network from the "northern" region to Mohenjo-daro is drawn with a line 6-points in width as 60% of the artifacts analyzed were assigned to sources there. A 4-point line was used to represent the 40% of artifacts from that site assigned to northern Rajasthan sources. Dashed lines (with a "?") indicate networks for which the steatite source is conjectural.

Temporal change was not illustrated on Figure 7.49 because to do so would have required either multiple maps or a single one with many more lines/ arrows and labels (this was attempted but was too busy visually). A phase-by-phase review of the steatite acquisition networks for Harappa is presented as part of the Chapter 13 summary of all geologic provenience studies presented in this book. Despite the lack of time depth, the figure does effectively depict the general acquisition patterns that are now evident for each site and for the Greater Indus region as a whole. With the final caveat – some or all of the networks defined here may change dramatically when additional steatite sources are incorporated into the geologic dataset; the following summary of the results is presented.

### Indus Tradition steatite acquisition networks (provisional)

The Harappans' Indus Tradition predecessors at Mehrgarh acquired black dolomitic steatite from a source that was probably located relatively close by that site in central Balochistan. They also used some ultramafic steatite from the Muslimbagh ophiolite of northern Balochistan. Prehistoric peoples dwelling somewhat farther to the north in the Loralai Valley likewise acquired raw material from the Muslimbagh ophiolite, as well as red dolomitic steatite that was either from some unreported local occurrence in northern Balochistan or, perhaps, one of the known

dolomitic deposits of Afghanistan. Later craftspeople at Harappa and the other Indus Civilization sites examined do not appear to have utilized steatite from any of the same sources as the ancient peoples of Mehrgarh or the Loralai Valley. However, the fragments analyzed from Tepe Hissar in Iran suggest that there were other dolomitic occurrences in the regions to the west of the Indus Valley from which some of the artifacts from Harappa and Mohenjo-daro could have *possibly* originated.

The earliest residents of Harappa (Ravi Phase / Period 1) used dolomitic steatite acquired through networks that extended 330 km northeast to Jammu and, perhaps, 500 km southeast to northern Rajasthan. By the Kot Diji Phase (Period 2) the largest percentage of raw material brought to the site was derived from dolomitic deposits located 400 km north in the Sherwan area of the NWFP. The Sherwan deposits remained the primary source of steatite for craftspeople at Harappa throughout the urban phase (Period 3) and into the Late Harappa Phase (Period 5). During that time, raw material continued to be brought from Jammu (through Period 3B) as well as other dolomitic sources in the "northern" region like Prang Dera in the Khyber Agency (through Period 5) and Daradar in the Kurram Agency (intermittently through Period 3C). Only very minor amounts of steatite were acquired from sources other than those to the north of Harappa. At least some raw material of ultramafic origin was obtained during Period 3A as indicated by a single fragment from the Wayaro source in the Las Bela ophiolite of southern Balochistan. A few examples of dolomitic steatite from periods 3B and 3C suggest that residents of Harappa had some degree of access to sources in northern Rajasthan at that time. Overall, however, Harappa's unfired steatite artifact assemblage is, in all periods and parts of the site, dominated by raw material acquired from "northern" region occurrences, in particular stone from the Sherwan area deposits (thus on Figure 7.49 the thickest network line is drawn from it to Harappa).

When provenience data from the other Indus Civilization cities and towns examined in this chapter are combined with that from Harappa, a much more complex picture of steatite acquisition in the Greater Indus region during the Harappan Period begins to emerge. We see that the residents of Nausharo in central Balochistan had access to the ultramafic deposits of the Wayaro area, which is around 380 km to the south in the Las Bela region. Interestingly and significantly, however, there is at present no evidence that raw material from those deposits was brought to Mohenjo-daro, despite them being the absolute closest sources to that city (≈ 200 km to its southwest). The single ultramafic fragment from Period 3A at Harappa, which was derived from a Wayaro area deposit, might therefore have been transported to that site along a network that passed through central Balochistan rather than Sindh (on Figure 7.49 I have drawn the conjectural route for that network through Nausharo).

Craftspeople working at Mohenjo-daro in Sindh and at Rakhigarhi in Haryana utilized dolomitic steatite from the same "northern" region sources overwhelmingly preferred by residents of Harappa (on Figure 7.49 the "northern" region network to those sites is conjecturally routed through Harappa). At Mohenjo-daro, they were also acquiring a smaller but significant portion of the raw material they used from dolomitic deposits in the northern Rajasthan region. A steatite seal from the site of Mitathal in southern Haryana is probably composed of stone from the same source area.

Dolomitic steatite from the "northern" region was apparently the preferred raw material as far south as Dholavira in Gujarat. However, ultramafic steatite from sources in eastern Gujarat and southern Rajasthan was also utilized at that city as well as at smaller Harappan settlements in the region like Nagwada and Gola Dhoro.

These are the steatite acquisition networks

of the ancient Greater Indus region as they are currently understood. There is every reason to expect that at least some of them might change when the comparative dataset of geologic sources is enlarged. Likewise, the regional picture of the networks is almost certain to become considerably more complex as artifacts from additional sites are analyzed. Nevertheless, even at this initial stage and in spite of the provisional nature of the provenience determinations, several major new insights into the acquisition and use of steatite by Indus Tradition peoples have been gained. To begin with, we have learned that, despite the wide distribution of potential sources around the Greater Indus region, craftspeople at Harappa, regardless of the chronological phase or part of the site in which they lived, mainly used steatite derived from a limited number of deposits located in the northern parts of Pakistan and India. Raw materials from sources in other regions, such as northern Rajasthan, southern Balochistan, and eastern Gujarat, were exploited to a limited degree at Harappa and/or at some other Indus sites. By and large, however, it appears that there existed an inter-regional distribution network for "northern" steatite that extended through the Punjab (perhaps even via Harappa) to Haryana, Sindh and Gujarat. Finally, it seems that Indus Tradition craftspeople, from the Neolithic Period at Mehrgarh through the Late Harappan Period at Harappa, were, with some notable exceptions, either mainly or exclusively using steatite of dolomitic origin.

The last insight is especially significant as it may help to explain, at least in part, why certain steatite sources, some of which were relatively close by Indus Tradition settlements and presumably assessable, were used either rarely or not at all. If stone that would become white when heated was desired (and it evidently was), then, as I discuss next, it appears that only certain dolomitic occurrences could have provided raw material with that property. I argue, therefore, that technological/aesthetic considerations, more than source proximity/accessibility, dictated which steatite sources were used.

### Heat-treating steatite and the desire for "white-firing" stone

Massimo Vidale noted (1989b: 180) that "in all Harappan craft production, a major emphasis [was] placed on the creation of artificial substances more than on the employment of precious, well recognizable raw materials." Few rocks or minerals would have satisfied the impulse to transform a raw material into something new better than steatite – a stone that undergoes significant physical changes when it is subjected to high temperatures. By heating steatite, Harappans and their Indus Tradition predecessors sought to greatly increase its durability by making it harder and dramatically alter its appearance by turning it white. Studying the mineralogical composition of heated artifacts enables archaeologists to assess and track the ability of Indus craftspeople to transform steatite in this way.

When sufficiently heated (also referred to as "fired" or "burnt"), steatite undergoes a variety of physical transformations. The mineralogical changes that result from the dehydration and thermal decomposition of talc (steatite's primary mineral constituent) are very well-documented (see Bose and Ganguly 1994 for a discussion of dehydration kinetics and Wesolowski 1984 for a review of various heating studies). Typically, talc decomposes to *enstatite* (magnesium silicate) and amorphous silica between around 900°C and 1000° C. At temperatures above 1100°C the amorphous silica will begin to crystallize as *cristobalite* (the high-temperature polymorph of quartz). Firing time, atmosphere and the composition of the raw material can all differentially affect the rate and temperature at which these changes take place, however. Experimental studies on steatite, similar to those conducted to replicate the firing conditions of Harappan ceramics manufacture (Kenoyer 1994a), are currently being undertaken by Dr. Mark Kenoyer and

Gregg Jamison at University of Wisconsin-Madison. Experiments also have been conducted by Barthélémy de Saizieu and Bouquillon (1994) and by myself (appendices 7.12 and 7.16) that involved the heating of raw steatite in electric kilns at different temperatures and the analysis of those samples using XRD. These studies (and the others cited above) have provided a framework for using the mineral phases detected in heated steatite artifacts to judge the approximate temperatures to which they were subjected (note that I am referring to objects made from massive steatite and not talc glazes or objects that some researchers believe to be made from powdered steatite "paste").

As noted near the beginning of this chapter, black steatite beads recovered in the very earliest (ca. 7000 BC) pre-ceramic Neolithic levels (Period I) at Mehrgarh constitute the first evidence for the use of that stone by Indus Tradition peoples. The first indication that Indus craftspeople might have begun to heat-treat steatite comes later in that same period at Mehrgarh (ca. 6200 BC – formerly the beginning of Period IB) in the form of white beads composed of *anthophyllite* and talc (see Barthélémy de Saizieu and Bouquillon 1994: 51 and Appendix 7.13 of this book). Those beads could be made from natural, unheated stone as anthophyllite (magnesium iron silicate hydroxide), like talc, is sometimes white in color (Deer *et al.* 1992: 232-236). On the other hand, an anthophyllite phase intermediate to talc and enstatite reportedly can develop when talc is heated between 667 and 745°C (Greenwood 1963). The beads could, therefore, represent the initial modification of steatite using relatively low heat. However, an anthophyllite phase was not replicated in either Barthélémy de Saizieu and Bouquillon's experimental heating study of Mehrgarh steatite (1994) or in my own (Appendix 7.12). For this reason, the heat-treatment of steatite during Period I at Mehrgarh must, at present, be considered unconfirmed.

Steatite was unquestionably being heat-treated by the late Neolithic (Period IIB ca. 5000 to 4500 BC) / early Chalcolithic (Period III – ca. 4500 to 3800 BC) periods at Mehrgarh. Using XRD, I analyzed two white beads recovered from a Period IIB level at that site (Appendix 7.13). Both exhibited minor enstatite peaks among the talc peaks, which suggest that they were probably heated to around 900°C for about one hour (or perhaps at a slightly lower temperature for a longer period of time). During Mehrgarh Period III, 93% of the beads in the site's assemblage are composed of heat-treated steatite (Barthélémy de Saizieu and Bouquillon 1994: 52). By the third millennium BC, Indus Civilization craftspeople were firing steatite at temperatures that clearly exceeded 1100°C (perhaps closer to 1200° C) as evidenced by artifacts analyzed from across the Harappan realm that in XRD scans exhibit cristobalite phases (Hegde *et al.* 1982: 243; Vidale 2000: 63 and Appendix 7.14 of this book).

Depending on its mineral composition, raw steatite can have a Mohs' hardness value of anywhere between around 1 (for types that are almost pure talc) to around 2.5 (*personal observations*). Low hardness combined with the compact, homogenous nature of good quality steatite allowed it to be sawn into thin chips that could be easily perforated and ground into beads (Vidale 1995), as well as shaped into seals (Rissman 1989) and tablets (Meadow and Kenoyer 2000) onto which inscriptions and/or various motifs were carved. However, in its raw form the stone is not very durable (it can easily be scratched with one's fingernail). By heat-treating steatite, Indus craftspeople could raise its hardness considerably. This has been documented Beck (1934: 77-82), Ritchie (1973: 48) Hegde and others (1982) and by myself (Appendix 7.16). The formation of enstatite imparts a steatite object with a hardness of between 5 and 6 (Deer *et al.* 1992: 155) and cristobalite of between 6 and 7 (ibid.: 457). Although increased hardness would have made such objects more durable, I would argue that this was not the main reason that they were heat-treated.

With the exception of the Neolithic period at

Mehrgarh, when unfired black steatite beads were most abundant (Barthélémy de Saizieu 2003: 24), the vast majority of *finished* steatite artifacts recovered at Indus Tradition sites are white in color and appear to have been heat-treated. Most are fired white completely throughout. Some artifacts, like stamp seals, have a white veneer that is the result of heating and either the application of a talcose glaze (Mackay 1931d: 379) or an alkaline surface treatment (Beck 1934: 80-81; Vidale 2000: 62). I tend to slightly favor the former explanation based on observations that I have made (Appendix 7.15). However, both techniques may have been used, perhaps at times in combination with one another. In any case, it is probably safe to conclude that, in most instances, a white appearance was the desired outcome when Indus Tradition craftspeople subjected objects fashioned from steatite to high temperatures.

Indus craftspeople apparently did not acquire and use raw steatite that was already white to begin with. None has been encountered among the nearly 3000 unfired artifacts and fragments at Harappa and to my knowledge none has been reported from other Indus Tradition sites (except, perhaps, the previously discussed white talc-anthophyllite from Mehrgarh, which may or may not be natural). Although it is possible that every scrap of white raw material was heated (and, thus, none was left to be recovered), such a scenario seems to me unlikely. It could be that this type of steatite, being the most chemically pure and least hard, was too soft and friable to be good carving stone. Or it might be that it was difficult to obtain since white stone does not tend to be found near the surface or at the easily accessible margins of steatite deposits (*personal observations*). However, it may be that Indus Tradition peoples preferred to use steatite that was colorful because it fulfilled an impulse to transform a raw material into something different. As heat is increased, the transformation of colored steatite to white is "visually impressive ... it might have been perceived as a magic process and might have suggested to the ancient craftspeople the idea of progressive purification" (Vidale 2000: 59).

In her doctoral dissertation on Indus Tradition pyrotechnologies, Heather Miller wrote (1999: 306) that "although found in various colors from white to creme to green to black, all varieties [of steatite] become white when fired to high enough temperatures." This would appear to be an unstated assumption of many South Asian archaeologists. However, this is simply not true. I have conducted a series of heating and characterization studies (Appendix 7.16) using geologic samples from several dozen of the steatite deposits examined in this study. Although these studies are still ongoing, one thing is already quite clear. That is, there are some types of steatite will become a pure bright white when fired and there are other types of steatite that will never become white regardless of how long or how high they are heated. Those types that do become white (or near white) when they are heat-treated are almost invariably from **dolomitic deposits**. Moreover, of the various dolomitic deposits examined in this chapter, those that exhibit the whitest firing steatite are the very same sources from which the majority of the unfired steatite artifacts at Harappa and Mohenjo-daro were predicted to have been derived. My apologies for the liberal use of emphasis in this paragraph but these are observations that go to the very core of two important issues raised by the results of the provenience study conducted in this chapter, which are: Why did Indus Tradition peoples mainly use dolomitic steatite and why did Harappans (at least those at Harappa and Mohenjo-daro) mainly acquire it from just a handful of deposits in the "northern" region when there were other, often closer sources? I now briefly look at both of these issues.

First. *Why the emphasis on dolomitic steatite?* In his examination of ancient steatite vessels from Eastern Northern America, James Truncer made a pertinent observation about the use of raw material from ultramafic and dolomitic (which he calls

*sedimentary*) deposits:

> No steatite vessel quarries have been documented at outcrops of sedimentary origin, a distinction not previously recognized by archaeologists. The use of ultramafic steatite is consistent with the largely held assumption that steatite vessels functioned as fireproof containers because steatite vessels of sedimentary origin would perform poorly in fire (Truncer 2004: 490).

I would argue that raw material of dolomitic origin was favored by Indus Tradition craftspeople for precisely the same reason that it was disregarded by vessel-makers in Eastern North America – because of the way it behaves when subjected to high temperatures. Indus Tradition consumers needed steatite that would become white when fired and my experimental heating studies (Appendix 7.16) indicate that dolomitic steatite is more apt to do that than ultramafic steatite. I strongly suspect that the reason for this has to do with, at least in part, the different concentrations of metallic elements that are found in the two kinds of steatite, i.e. – very high concentrations in stone of ultramafic origin vs. very low concentrations in dolomitic steatite. In my heating experiments, the ultramafic geologic sample that was lightest in appearance (although not pure white) after being fired came from the Urgasai Nasir deposit (source code ZUN) of northern Balochistan (see Figure 3 in Appendix 7.16). Recall from the CDA of the full geologic set (Figure 7.31) that this was one of the ultramafic deposits that partially overlapped with the dolomitic ones because some samples from it had untypical low concentrations of certain metallic elements.

So in both parts of the ancient world we see that technological considerations – the need for white-firing steatite in the Greater Indus region and for fire-resistant material in Eastern North America, influenced which kinds of steatite deposits were exploited.

Now on to the second issue – *why did residents of Harappa and Mohenjo-daro acquire the majority of their dolomitic steatite from deposits in the "northern" region?* For consumers at Mohenjo-daro, deposits in northern Pakistan and India definitely were not the closest occurrences of dolomitic steatite. With regard to Harappa, some of the "northern" sources (those in Jammu) did constitute the nearest locations where steatite of that kind could be acquired. However, the others (those in the Sherwan zone and in the FATA) were more or less the same distance from the site as the dolomitic deposits of northern Rajasthan. In fact, those other sources may have been more difficult to reach than the ones in Rajasthan due to the fact that there are many more rivers and mountain ranges that lie between them and Harappa. So why, then, of all the potential dolomitic sources in the Greater Indus region, was steatite from a few deposits in northern Pakistan/India the preferred raw material at those two Harappan cities? After having heat-treating samples from most of the dolomitic deposits examined in this chapter (Appendix 7.16, Figure 8), the answer would seem to be that <u>steatite from "northern" region sources fired the whitest.</u> Thus, I would argue that the aesthetic requirements of Harappan craftspeople (their desire for white-firing stone), more than source proximity and/or difficulty of access, probably dictated which dolomitic steatite deposits were exploited.

The heating experiments reported in Appendix 7.16 have also provided information that may help to clarify patterns suggested by the cluster analysis of the full geologic and archaeological steatite sets. Recall that on the dendrogram (Figure 7.36 and Appendix 7.9) there are several large groups of the artifacts that exhibit a degree of compositional homogeneity that is more pronounced than even that of geologic samples collected from individual steatite deposits. I suggested that those closely related artifact clusters

possibly represent raw material exploited from a very restricted area within an occurrence, such as a single outcrop, vein, pit or mine. Heating experiments indicate that steatite from within the individual deposits of the Sherwan zone – the source that the majority of artifacts from Harappa were predicted to belong to, is itself variable in terms what will become white and what will not. Samples from the Chelethar (SC) and the Khanda Khu (SKK) deposits became white in one heating but failed to do so in another (Appendix 7.16, figures 3 and 8). When sampling those locations, both of which extend over several hundred meters and encompass numerous pits and mine shafts (both old and modern), I was concerned with documenting intra-source variability and so collected a spatially wide range of material from them. However, it is highly likely that prior to transporting just any seemingly good-quality stone over 400 km to Harappa, whoever was extracting steatite from those (or any other) deposits during the prehistoric period would have located the specific, perhaps very restricted places within them where the whitest-firing material occurred. The intensive and sustained exploitation of raw material from such intra-source locations *could* account for the clusters of highly compositionally similar artifacts evident on the CA dendrogram.

Before concluding it is important to again acknowledge that eight of the 179 steatite artifacts analyzed in this chapter were determined not to be composed of dolomitic steatite. Although many of those were finished beads or other objects like the BMAC wig that were never meant to fired, one of them – the Gola Dhoro seal (Figure 7.7 F), clearly has been. That artifact does not have a bright white exterior like most Harappan steatite seals and beads, but it is much lighter in appearance than any of the samples from ultramafic deposits that I heat-treated in Appendix 7.16 (save for the previously mentioned ZUN sample, which [1] was white to begin with and [2] had low concentrations of metallic elements). There are a small number of finished, heat-treated steatite seals from Mohenjo-daro that exhibit a muddy red-colored exterior (for examples see Shah and Parpola 1991: color plates 7, 15 and 17) that resembles the post-firing appearance of many of the geologic samples I tested (Appendix 7.16, Figure 3B). Such seals were probably carved from and/or glazed with steatite that was not predisposed to fire to the white color that was desired by their manufacturers. The very light-gray color of the Gola Dhoro seal indicates that its makers had either succeeded in identifying/acquiring a type of ultramafic steatite that would fire near white *or* had the ability to lighten the exterior of non-white firing stone, perhaps by employing the same technique used to bleach white designs onto carnelian beads (Mackay 1933). I attempted to whiten that kind of steatite using different alkali solutions (detailed in Appendix 7.16) but was unable to affect any change in the stone's appearance. Although my failure does not prove that Indus Tradition craftspeople were incapable of bleaching stone of ultramafic origin, it does appear as if those working at Harappa (and probably Mohenjo-daro too) either could not or chose not to whiten this kind of steatite. Had they done so on any significant scale then odds are that more than one example of ultramafic stone would have been identified among the 139 fragments and unfired artifacts (≈ 5% sample of the sub-assemblage) that were analyzed from the site. The real point, however, is that they did not have to. The results of the provenience study indicate that people at those cities acquired the majority of their steatite from "northern" region sources that, as shown by the heating studies, contained raw material that was predisposed to fire white.

What then of the Gola Dhoro ultramafic steatite seal? Perhaps it indicates that the makers of that object did not have access to white-firing stone from the "northern" region and, like the Harappans of Nagwada, had to make due with the nearest available steatite, which was ultramafic in origin. This may

have prompted them to invent or adapt whitening technologies that their fellow Harappans in the Indus Valley either did not possess or, more likely, did not need to use on steatite (because they had access to white-firing stone).

## CHAPTER CONCLUSION

From the Ravi through the Late Harappa phases, residents of Harappa acquired almost all of the raw steatite they used from dolomitic sources located in the northern part of present-day Pakistan and India. Craftspeople in different parts of the site seem to have had access to raw material from that same broad source area. "Northern" dolomitic steatite was transported as far south as Mohenjo-daro but apparently was not used in Gujarat. In the next chapter, I examine agate – a broad variety of stone that appears to have been transported from several sources in Gujarat to Harappa and other sites in the Indus Valley.

# CHAPTER 8

# AGATE ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: SOURCING HARAPPAN AGATE

The roughly 4700 finished objects (mostly ornaments but also the occasional stone weight) and pieces of raw material or manufacturing debris from Harappa that have been designated *agate* or *jasper* exhibit a bewildering range of macroscopic variability (recall Figure 4.3 C for just a handful of examples). Although HARP co-director Dr. J. Mark Kenoyer has developed an intricate coding system for describing such variation, visual attributes alone cannot be used to identify their geologic sources. As was the case for steatite, multiple macroscopic types of agate and jasper are usually found at source locations (*personal observations*) and, in fact, often are present in individual specimens (note, for instance, the variegated appearance of some of the agate samples pictured in Figure 8.28). Moreover (and also like for steatite), Indus craftspeople likely altered the original appearance of certain sub-varieties of these microcrystalline silicates when they heat-treated them (described in Kenoyer *et al*. 1991). The secondary contexts from which agates and jaspers are frequently obtained, like riverbeds and conglomerates, may contain materials that formed across extremely wide areas and in very different geologic episodes and/or environments. Recent attempts to provenience of *carnelian* (red-orange agate) artifacts using PIXE analysis (Theunissen *et al*. 2000) and LA-ICP-MS (Insoll *et al*. 2004) have produced largely equivocal results. It was for all of the above reasons that I initially approached the sourcing of this material sub-assemblage with low expectations of success.

In order to make this aspect of my research more manageable, I narrowed the focus to just agate and a very specific research question. I decided to evaluate the long and widely held "assumption" (Ratnagar 2004: 146) that Harappans derived their agate primarily from sources in Gujarat; most probably the deposits of the Ratanpur area in the southern part of that Indian state (Allchin and Allchin 1997: 173; Asthana 1993: 274; Biwas 1996: 49; Lal 1997: 163-164; Pascoe 1931: 681; Vidale 2000: 42). Using INAA, agate samples collected from Ratanpur and two other sources located in northern Gujarat were analyzed. These were then compared, using CDA, to one another and to agate artifacts from the prehistoric site of Shahr-i-Sokhta in eastern Iran, which were treated as proxy samples for sources in that distant region. Good to excellent (≈ 85 to 95%) statistical separation between grouped samples from these sources/proxy sources was achieved. When agate artifacts from Harappa and five other Indus Tradition sites were compared to them, it was found that although most are analogous to geologic samples from the Gujarati deposits, very few appear to be from the Ratanpur source. The results also indicate that Harappans may have been acquiring some agate from sources in regions other than Gujarat.

In this chapter, I recount what, despite my initial expectations, has turned out to be a successful provenience study of Harappan agate. It is presented in two main parts. In the first, I discuss the formation of agate and agate deposits and then outline potential sources of that stone in the Greater Indus region and beyond. I begin the second part by presenting the geologic dataset and the agate artifacts (from Harappa and five other sites) that are compared to it. Multiple discriminant analyses involving different

combinations of source samples are then carried out and provenience determinations are assigned. Afterwards, the results are scrutinized and, when necessary, qualified. In the final section, I discuss their implications for future research of this kind and summarize the provisional conclusions.

## GEOLOGY AND POTENTIAL SOURCES OF AGATE IN THE GREATER INDUS REGION AND BEYOND

Even after centuries of study, "the origin of agate remains incompletely understood" (Götze *et al.* 2001: 527). Nevertheless, a brief overview of what is known about the stone's formation and the primary and secondary geologic contexts in which it is found is useful for the upcoming outline of the its potential sources in the Great Indus region and beyond.

### The formation of agate and agate deposits

Agates are translucent microcrystalline sedimentary rocks that form when silica precipitates in cavities within some type of host rock. The mechanisms behind their growth, frequent banding and other distinctive characteristics are the subjects of much debate (for detailed discussions and different views see Fallick *et al.* 1985; Heaney and Davis 1995; Merino *et al.* 1995; Moxon 1996; Pabian and Zarins 1994; Wang and Merino 1990, 1995). The rocks in which agates form may also be sedimentary (limestone, dolomite, claystone) but they are more commonly igneous (Luedtke 1992: 31-32; Pabian and Zarins 1994: 7). As certain types of volcanic lavas and tuffs cool, cavities (vesicles) form within them that later become filled in with secondary minerals like calcite, crystalline quartz and/or microcrystalline quartz – i.e, agates and jaspers. The filled cavities are called *amygdales* and the igneous host rocks containing them are described as *amygdaloidal* (Lapidus and Winstanley 1990: 24-25). A good example of this primary geologic context for agates (Figure 8.1) and other microcrystalline silicates would be the "highly amygdaloidal" volcanic trap (basalt) rocks Fedden described (1885: 20, 62) in Gujarat's Saurashtra Peninsula. Although I encountered only jasper-filled amygdales (Figure 8.2) during my visit to that area, Fedden reported agate, moss agate and chalcedony in the region to the northwest of Rajkot.

As their host rocks erode, loosened agates (many retaining the nodular shapes of the cavities in which they formed) fall away. These then may be carried by fluvial action or other processes and end up in a range of secondary geologic contexts (Figure 8.3). In Gujarat at least (*personal observation*), it is not uncommon to encounter agate nodules or fragments when walking across the fields of India's famously rich "black cotton soils," which formed due to the decomposition of the basaltic rock of the Deccan Traps (Hegde 1989). In other places, such as sources that I will shortly discuss in eastern Kutch, all remnants of host rocks have disappeared leaving behind only loose "agates ... so numerous as sometimes to form a coarse gravelly layer on the surface" (Wynne 1872: 116-117). Loose agates, often carried far from their original host formations, can be found in the beds of certain rivers, streams, nalas and wadis across South Asia, the Iranian Plateau and Arabia. In some places, fluvially transported microcrystalline silicates have been deposited and reconsolidated. The famous Ratanpur area sources are part of the early Miocene epoch conglomerate called the *Babaguru Formation* (Gadekar 1977). P.K. Chatterjee noted (1963b: 166) that "chalcedonic silica, carnelian, chalcedony, chrysophrase, plasma, bloodstones, onyx, jasper, agate jasper, flint, chert, etc ... [all] occur" within it.

It was extensive and materially diverse secondary agate deposits like the Babaguru Formation that initially caused me to be skeptical about whether or not it was possible to source this variety of stone. That



**Figure 8.1** Primary geologic context agate: an amygdale of chalcedony in basalt, near Ellora, Maharashtra.



**Figure 8.2** Amygdales of jasper in basalt, near Khokhari Village, Jamnagar District, Gujarat.

**Figure 8.3** Secondary geologic context agate.



**A**. Agate-filled agricultural field at Undari, Yavatmal District, Maharashtra.



**B**. Large agate nodule at Undari.



**C**. Agate nodules in the Godavari River near Paithan, Aurangabad District, Maharashtra.



**D**. Detail of agate nodules at Paithan.

particular formation is thought to be the remnant of a "fluvial delta" (Gadekar 1977: 555), most likely of a river that drained the west-central Deccan Plateau, not unlike the Narmada River does today. Agates and other microcrystalline silicates deposited within it could, therefore, have come from primary sources occurring over an enormous geographic area. Moreover, the Deccan Traps from which those stones eroded are not a homogenous geologic unit but rather succession volcanic events (see Sukheswala *et al*. 1972: Fig. 2a for a diagram depicting the layered amygdaloidal basalts of the western Deccan Traps). The Babaguru Formation might well then contain agates that formed in multiple basalts of slightly different ages and chemistries. As I stated in the introduction, it has thus far been possible differentiate Ratanpur agate samples from those of other deposits in Gujarat and elsewhere. It is important to realize, however, that as additional sources are analyzed, particularly from other locations in the Deccan Traps, this *may* become increasingly more difficult.

**Potential Harappan agate sources**

In this section, the agate sources that Harappans potentially may have had access in the Greater Indus region (Figure 8.4) and beyond (Figure 8.5) are outlined. We begin with an overview of Gujarat and then briefly examine deposits elsewhere in the Deccan Traps. Minor agate occurrences to the west and north of the Indus Valley are then discussed followed by potential sources in regions that Indus Civilization peoples had clear contacts with such as Afghanistan, southern Central Asia, the Iranian Plateau and eastern Arabia.

***Agate deposits in Gujarat***

There are a number of reasons why Gujarat (Figure 8.6) is assumed to have been an important source area, perhaps even the primary source area, for the agates used by Indus Civilization peoples. Firstly, Harappans were present there; often (as I show below) in very close proximity to some significant occurrences. In fact, ornamental microcrystalline silicates were probably among the resources (some other being marine shell, salt and pasturage) that attracted them to the region in the first place. Secondly, although occurrences of agate can be found in many parts of Asia, the extent, diversity and sheer richness of sources in Gujarat is unparalleled. The region could aptly be characterized as the "Saudi Arabia" of agate. Lastly, Gujarat was a historically important source area. Greek (McCrindle 1885: 77, 334; Schoff 1912: 42), Mughal (Khan 1756: 250) and early European colonial (Barbosa 1517: 66-67; Foster 1906: 52, 178) records all make reference to the agate resources there. The city of Khambhat (Cambay) has been a major center for the manufacture of agate ornaments since at least the 16th century (Arkell 1936; Campbell 1880: 206-207) and the traditional methods still employed there have been the subject of several ethnoarchaeological studies (Kenoyer *et al*. 1991, 1994; Possehl 1981; Roux 2000).

Throughout the historic era, the preeminent agate source within Gujarat has been the deposits around Ratanpur (Figure 8.7) in the southeast part of the state (Allchin 1979a; Ball *et al*. 1881: 506-507; Bose 1908; Francis 1983; Sahni 1948). This review begins there.

*- Southeastern Gujarat – Ratanpur area deposits*

Among the low hills around the village of Ratanpur, Bharuch District, Gujarat (Figure 8.8), there are hundreds of agate mining pits and shafts (Figure 8.9) sunk into the Miocene conglomerate of the Babaguru Formation. Although these workings are often referred to as the "Rajpipla" deposits/mines (as they were within the confines of that princely state prior to 1947), "Ratanpur" is a more appropriate designation (Ball 1886: 238). Mining locations having published geographic coordinates (Chatterjee 1963a: 166; Insoll *et al*. 2004: 1162) are plotted on Figure 8.7. Trivedi noted (1964: Map 2) most of these localities,

**Figure 8.4**: Greater Indus Valley region agate occurrences and sites discussed in this chapter.




**Figure 8.5**: Agate sources outside of the Greater Indus region.




**Figure 8.6** Agate sources, archaeological sites and modern towns in Gujarat.

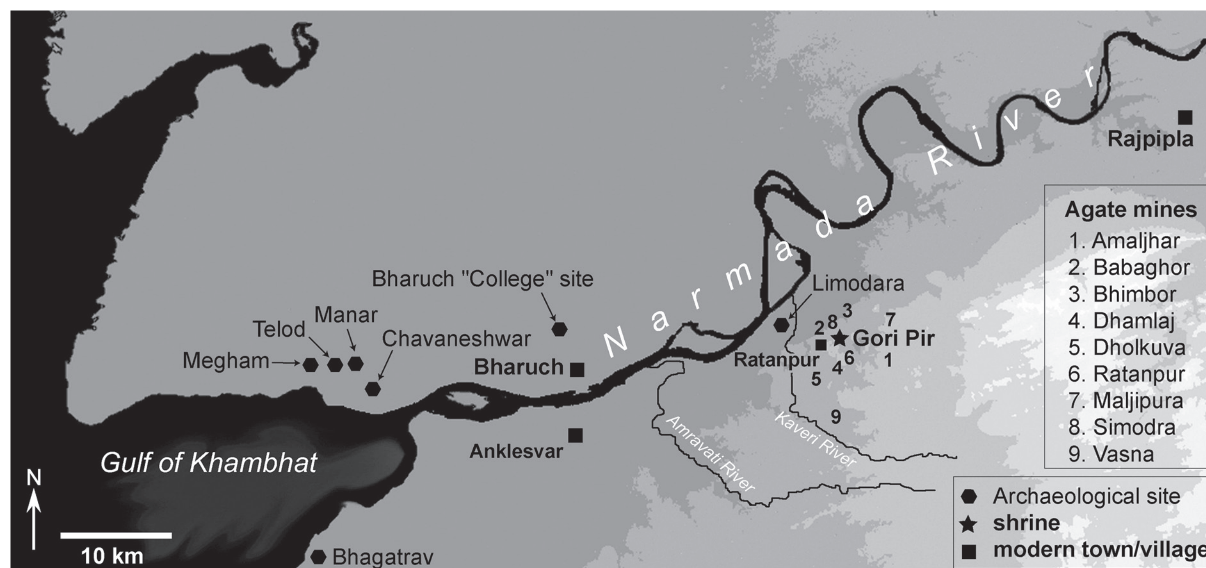



**Figure 8.7** Ratanpur area agate sources and archaeological sites.

as well as around a half dozen others, in his review of the Khambhat bead industry (Figure 8.10), which to this day consumes tons of Ratanpur agate (Figure 8.11). All occur within fifteen kilometers of the hilltop tomb/shrine of Gori Pir (or Baba Ghor) – a Muslim saint who is said to have come from Africa in the 15th century and established bead-making operations at nearby settlements such as Limodara (Francis 1986; Kenoyer and Bhan 2005). M.R. Sahni (1948: 248-250, 253) noted that agates could also be obtained from the beds several small rivers (the Karad, Kaveri and Amravati) southwest of the Ratanpur area as well as to the east along the banks of the Narmada River near Rajpipla town. The nodules found in the former are said to be "rarely, if ever, of large size" (ibid.: 253). Those nearer to Rajpipla, while larger, tend to be



**Figure 8.8** Ratanpur Hills area, Bharuch District, Gujarat.



**Figure 8.9** Agate mine shaft sunk into the Miocene conglomerate (Babaguru Formation).



**Figure 8.10** Worker in Khambhat, Gujarat making beads roughouts using Ratanpur agate.



**Figure 8.11** Sacks of Ratanpur agate in Khambhat.

composed of clear chalcedony (*personal observations*).

Samples for this study were collected from pits (figures 8.12 and 8.13), shafts and tailings along a three kilometer zone extending from the base of Gori Pir Hill south-southeast to point #6 on Figure 8.6. Because the Babaguru Formation is a materially diverse secondary context agate deposit (discussed above), an attempt to assess geochemical variation across that zone was deemed to have little utility. All samples from this occurrence are, therefore, treated as coming from a single source, which is simply designated "Ratanpur."

It is unclear if Harappans might have had direct access to agate from the Ratanpur area deposits. Lothal – the nearest site that is inarguably an Indus Civilization settlement, is located around 130 km to the northwest of Gori Pir Hill. A handful of prehistoric sites are encountered as one moves west from Ratanpur toward the mouth of the Narmada River. Possehl identifies these as "Sorath Harappan" settlements in his *Gazetteer of Indus Age Sites* (Possehl 1999: Appendix A). If Indus Civilization peoples did acquire Ratanpur agate then doing so likely entailed interaction with the residents of these sites (or of other similar sites in the area) regardless of whether or not they were fellow Harappans or members of a separate, locally distinct cultural phase (recall the discussion on pp. 46-47).

*- Northern Gujarat*

The agate sources of northern Gujarat would have been the ones most directly accessible to Indus Civilization peoples. There are number of occurrences (at Antarjal, Bhuvad, Dagala, Khera and Khegarpur) reported in central Kutch (Geological Survey of India 2001a: 47), which have not been described in detail but are likely derived from nearby outliers of the Deccan traps. Many are located in close proximity (less than 10 km) to Harappan settlements like Jhangar (Joshi 1990: 418) and Khedoi (IAR 1976-77: 15). I visited a several of these occurrences and observed only fragments (some quite large) of milky



**Figure 8.12** Whenever possible, agate samples were taken from the interiors of mine shafts at Ratanpur.



**Figure 8.13** Removing a sample of agate-carnelian from the Miocene conglomerate at Ratanpur.




**Figure 8.14** Fragments of milky white agate-chalcedony near Antarjal, central Kutch District, Gujarat.

white agate-chalcedony (Figure 8.14).

Toward the east, A.B. Wynne noted (1872: 72-73) that the "agate-bearing laterites of North-Eastern Kutch are far removed from the stratified [Deccan] traps, resting to their entire exclusion upon Jurassic rocks … the source of the agates rather widely disseminated in them is somewhat mysterious, there being no evidence that the bedded traps ever existed in that part of the district, nor does any outlier of them occur within a distance of about forty miles" (≈ 65 km). Occurrences of this type are found around Adesar (Geological Survey of India 2001a: 47), northwest of Rapar on the eastern shore of the Great Rann (Merh 1995: Figure 17) and near Khandek village. A deposit on Mardak Bet in the Little Rann (Trivedi 1964: 10-11) is, however, associated with trap rock (Satyanarayana and Narasimha Rao 1955: 88). The latter two sources mentioned were sampled and analyzed for this study.

Khandek, Eastern Kutch

The Khandek agate source (Figure 8.15) was first brought to my attention by R.S. Bisht, the excavator of the Harappan city of Dholavira, which is located some 70 km to its west-northwest on the island of Khadir. Ravaji Solanki – the local stone expert (pattarwala) at Dholavira provided directions to Khandek village and his brother Narsingh, who resided there, guided me to the source itself (located at N 23° 38' 28", E 70° 52' 22"). A pavement-like layer (Figure 8.16) of loose agates (natural carnelian, yellow-brown agate, clear chalcedony, moss agate) and other microcrystalline silicates (red, green, brown and variegated jaspers) covers an area of perhaps four hectares (roughly 200 x 200 meters) just east of the village. This source is located around five kilometers from the small fortified Indus Civilization settlement of Surkotada (Joshi 1990). Although no clearly prehistoric workings or cultural materials were identified, numerous "window" flakes (pieces



**Figure 8.15** With Narsingh Solanki at the Khandek agate beds, eastern Kutch District, Gujarat.



**Figure 8.16** Pavement-like surface of the agate bed at Khandek.

of cortex that were struck from nodules in order to observe the quality of the agate inside) were found that indicate it had been exploited for materials at some time in the past.

Mardak Bet, Little Rann of Kutch

The agate deposits on the island (bet) of Mardak, in the salt marsh southeast of Kutch known as the "Little Rann" (Figure 8.17), can be difficult to reach due to seasonal flooding of the area surrounding them (Trivedi 1964: 11). A sampling trip with Arun Malik (a PhD student at Maharaja Sayajirao University) in early 2003 ended with us stuck in the mud within sight of the island (Figure 8.18). A second attempt (this time with Malik and Dr. Kuldeep Bhan) later that same year just prior to the summer monsoons was successful.

Mardak Bet is a thinly-shaped, east-west oriented island around 12 km in length with a maximum width of about 1.25 km. The agate beds are found in two main areas. The most extensive is located near the island's constricted mid-section, which Malik designated "nana" (Figure 8.19). Another occurs 3 km to the east, around the base of its highest hill (≈ 40 m above the salt flats), which was designated "mota." A wide range of microcrystalline silicates are found at both locations. Brownish-gray agate is by far the most abundant type but nodules of natural carnelian, clear chalcedony and moss agate are not uncommon. Red, green, yellow-brown and variegated jaspers (including bloodstone) are also found. Mardak Bet is the only source visited at which I have encountered a distinctive type of brown and white parallel-banded agate-jasper that was used by beadmakers at both Dholavira (*personal observations* 2007) and Harappa (for an example see Kenoyer 1998: Figure 6.44).

No prehistoric settlements are known to exist on Mardak Bet and no ancient workings in the island's agate beds were identified during our short visits to them. Mining pits and sorting areas (Figure

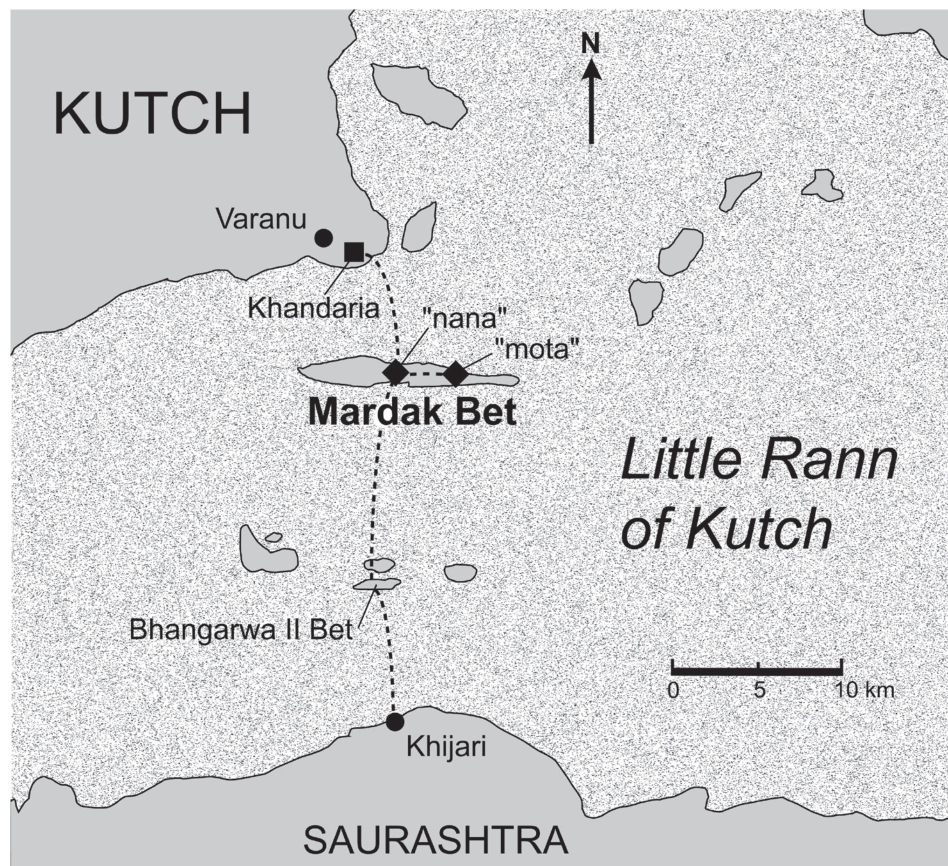



**Figure 8.17** Little Rann of Kutch, Gujarat.



**Figure 8.18** First attempt to reach Mardak Bet in the Little Rann of Kutch, Gujarat.



**Figure 8.19** Pit in agate bed at "nana" Mardak Bet.



**Figure 8.20** Discarded nodules and window flakes at "mota" Mardak Bet.



**Figure 8.21** Agate and jasper flakes along with ceramics found on Bhangarwa II Bet, 12 km south of Mardak Bet.

8.20) related to modern extraction activities (Singh 1999: 216; Trivedi 1964: 10-11) have likely obscured any evidence of earlier ones. There are, nonetheless, indications that ancient peoples did exploit these deposits. Numerous agate and jasper flakes, some with a heavy patina suggesting great antiquity, were found on the hillside at "mota" Mardak Bet. Similar flaking debris was also observed 12 km to the south on Bhangarwa II Bet (Figure 8.21). That small island was likely a processing point for raw material obtained at Mardak Bet as there are no agate sources on or nearby it. Finally, I have been informed by R.S. Bisht (*personal communication* 2004) that agate and jasper artifacts visually identical to the material occurring at Mardak Bet (which he has explored firsthand) are evident at the Harappan site of Khandaria (Bisht 1989a: 267), which is located less than 10 km away near the village of Varanu on the northern shore of the Little Rann.

*- Eastern Gujarat and Saurashtra*

There are a number of other agate occurrences in Gujarat that, even though they were not sampled and/or analyzed for this study, should be noted as potential Harappan sources.

Multiple types of microcrystalline silicates (including some that can be heat-treated to produce carnelian) occur around Kapadvanj, in the eastern part of the state (Campbell 1879: 15), approximately 100 to 110 km northeast of Lothal. Nodules as large as ten pounds (≈ 4.5 kg) were reportedly once gathered near that town as well as from the bed of the Májam River, some twenty kilometers to the north (Campbell 1880: 199-200). Samples were collected from the Kapadvanj source in early 2009 but have not yet been analyzed.

A wide range of microcrystalline silicates, both occurring in and eroded from amygdaloidal basaltic rocks of the Deccan Traps, are found across the Saurashtra Peninsula (also known as Káthiáwár). Below I discuss just a few of the more notable occurrences.

A black and white veined material that was once the "most valued Cambay agate" (Campbell 1880: 200) occurs some 50 km west-southwest of Lothal around Ránpur village in the Ahmedabad District (not to be confused with the site of Rangpur [Rao 1963], which lies 22 km east of that settlement along the Bhadar River). The geographic coordinates provided by Chatterjee (1963a: 166) suggested that the actually source of this stone might be at nearby (5 km east) Nágnesh village where an exposed "bed of sphæroidal felsite, whose nodules have a nucleus of chalcedony" was reported (Fedden 1885: 26). However, during two different trips to that area I failed to locate any gem-quality agate.

Miocene conglomerates (Figure 8.22) in the vicinity of the towns of Bhavnagar and Gogha in the Bhavnagar District are "agatiferous" and closely related to the those of the Ratanpur area (Mohan and Chatterji 1956: 351; Fedden 1885: 110), which lay directly opposite to them across the Gulf of Khambat. Although the agate nodules found here are of excellent quality, they could have only been used to make very small beads as none observed were larger than three centimeters in size (Figure 8.23). Similar conglomerates containing "agate, chalcedony, flint, jasper, etc." are also reported farther south near Lakhanka and between Badi and Chhaya (Gujarat State Gazetteers 1961b: 22). Still further south, in the southern part of the Amreli District (not pictured on Figure 8.6), "milky white chalcedony and agate form geodes in the traps near Khamba, while pebbles of agate and chalcedony are found loose in the nala between Hemal and Sokhda" (Gujarat State Gazetteers 1961a: 17).

The Rajkot and Jamnagar districts of northern Saurashtra are especially rich in ornamental microcrystalline silicates. Chatterjee compiled (1963a: 167 – from Fedden 1885 and other sources) information on a number of locations (Khijaria, Latipur, Jiwapur, Badanpur, Khakhra, Varatia) at



**Figure 8.22** Miocene agate gravel beds near Gogha, Bhavnagar District, Gujarat.



**Figure 8.23** Detail of tiny agate nodules in the gravel beds near Gogha.

which agate, moss agate and chalcedony occurred, both as loose nodules and in amygdaloidal trap rock. The jasper source near Khokhari village that was highlighted earlier (Figure 8.2) is also located in this region as are numerous ancient settlements including Kuntasi (Dhavalikar 1992) and Gola Dhoro (Bhan *et al*. 2004). Storage bins containing sorted blocks of variegated jasper found at the latter site provide evidence that Harappans were acquiring microcrystalline silicate resources from this region.

***Agate deposits elsewhere in South Asia***

Gujarat may have been the richest agate source area in South Asia but it was not the only one. In this section, I review other potential sources in the Subcontinent with a particular emphasis on those in and adjacent to Greater Indus region.

*- Peninsular, Central and Eastern India*

In addition to the agate deposits of Gujarat, P.K. Chatterjee noted, in his *Annotated Index of Indian Mineral Occurrences* (1963a: 165-168), sources in the states of Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Mysore, Orissa, Rajasthan and Uttar Pradesh. There is no need to review all of them in detail here as most are unlikely to have been utilized by Indus Civilization peoples. For example, the varied agate deposits in the Deccan Traps of central Maharashtra (recall Figure 8.3) are important raw material sources for Khambhat lapidaries today (Vidale 2000: 42). Those same occurrences might have even been exploited by the Late Harappan peoples who were dwelling around 80 km from them at Daimabad (Sali 1984). However, they are unlikely to have been utilized to any great extent (if at all) by Indus Civilization beadmakers. To my knowledge there are few (if any) types of ornamental microcrystalline silicates in Maharashtra or elsewhere in Peninsular India that are not also available in Gujarat. There would, therefore, be little reason for Harappans in the Indus Valley proper to bypass source areas like Kutch, Saurashtra or Ratanpur, in order

to obtain agates from that region. They were even less likely to have acquired such materials from still more distant deposits in southern India. The agate occurrences of Central India, being comparatively near the Greater Indus region, would have been much more viable alternate sources for residents of Harappa.

Chatterjee noted (1963a: 168) that "agate, jasper, carnelian, moss [agate] and onyx are common in the beds of the Banas and other rivers" in eastern Rajasthan. In this same general area, Hardie described (1829: 117-119) primary context agate-jasper at Sawah and at Buneerah. Malwa-Rajasthan Tradition Ahar-Banas culture complex (Shinde *et al*. 2005) peoples at settlements like Gilund, Balathal and Ahar would have been in close proximity to these occurrences. Slightly farther to the east, the agate sources of the Sehore-Bhopal region in western Madhya Pradesh (Chatterjee 1963a: 168) may have been among those exploited by beadmakers working at Ujjain during the historic era (Banerjee 1959) and at nearby Kayatha during the Chalcolithic Period (Ansari and Dhavalikar 1971). Harappan-like large storage jars and a cache of 40,000 steatite microbeads (ibid.: 338, 342, Plate 7) recovered in Period 1 (ca. 2000 to 1800 BC) levels at the latter site indicate that people dwelling there had contacts with later phase Indus Tradition peoples. It is not clear if those links extended from Kayatha north-northwest toward Harappan/Late Harappan groups in the Upper Indus Basin/Gangetic Basin region or southwest toward those in Gujarat. What is clear is that trade networks connecting the Malwa Plateau region with the northern Subcontinent (the Ujjain to Taxila route – Eggermont 1966) were firmly in place by the early historic era. The storage jars and steatite beads from Period 1 at Kayatha may represent the initial establishment of those northern networks. This is important for the current discussion because it was around this time that interaction between peoples of the northern and southern reaches of the Greater Indus region diminished (Kenoyer 2005b), thus making the microcrystalline silicate resources of Gujarat unavailable to beadmakers at northern cities like Harappa. The agate deposits of the Malwa Plateau region might have become important new sources for them when this happened.

It is also quite possible that some agate from sources adjacent to the Gangetic Basin, such as those in the Mirzapur and Banda areas (noted on Figure 8.5) of the Vindhya Range (Chatterjee 1963a 168; Kumar 2005: 363; Srivastava *et al*. 1983), ended up at Indus Civilization sites in Haryana or the Punjab. I have recently examined (Law *in preparation*) the stone artifacts from the early levels of Lahuradewa, District Sant Kabir Nagar, Uttar Pradesh (Tewari *et al*. 2006). Those levels are filled with steatite beads that would appear to be Harappan in origin as well as beads and tools evidently made from agate available in the Gangetic region. If the steatite beads were indeed coming from the west then agate from sources in the east could very well have been moving in the opposite direction. This movement might have been even more pronounced during the first half of the second millennium BC, as the Late Harappan demographic center of gravity in the northern part of the Indus world shifted toward the east (Possehl 1997c).

*- Northern deposits*

Agate deposits located in the mountainous regions north of the Upper Indus Basin are small in size, widely scattered and, in certain instances, extremely remote. Most are associated with volcanic rocks. Two occurrences – one in the Khewra Trap of the eastern Salt Range and the other in the Pir Panjal Trap of western Kashmir, were previously (p. 153) noted as possible sources for the purplish-colored chert/chalcedony found in Early Harappan levels at Harappa. "Small geodes of reddish quartz and chalcedony" were observed (Wynne 1878: 75) in the former formation while "pear-shaped amygdules of chalcedony, reaching to two or three inches in length" were reported (Lydekker 1883: 218) to occur in the latter. In the NWFP, agate nodules derived from with

island-arc volcanics are found in the Dir Kohistan area (Kazmi and Jan 1997: 477). Their appearance has not been described, however. Godwin-Austen reported (1867: 362) that "fine agates and cornelian are to be found in a small ravine" at Kyamgo Traggar, north of Pangong Lake not far from the Tibet-Kashmir border. This occurrence lies over 5100 m above sea level.

It is quite possible that agates from these northern sources found their way into bead workshops at Harappa. In this book, I demonstrate that both Early Harappan and Harappan residents of the site were acquiring other raw materials derived from sources in the Salt Range (chert and alabaster) and western Kashmir (lead and, perhaps, alabaster). The Dir agate source area lies along what may have been a route from the Indus Valley to northern Afghanistan and the Harappan outpost of Shortughaï. Finally, extreme elevation evidently did not impede Northern Neolithic peoples, such as those periodically dwelling at Burzahom in the Kashmir Valley, from crossing the plateau of Tibet during the prehistoric period (Xu 1991). Early Harappans and/or Harappans at settlements in the Himalayan foothills such as Sarai Khola and Manda might have indirectly acquired agates from remote sources like Kyamgo Traggar through interaction with those northern highlanders.

*- Sindh and Balochistan*

The agate deposits of Sindh and Balochistan, like those in the north, are small and sporadic. A source is reportedly located at Nagar Parker (Kazmi and Jan 1997: 477) in the southeastern corner of Sindh (noted on figures 8.4 and 8.6) near the northern shore of the Great Rann of Kutch. The material found there and its mode of occurrence has not been described but it is quite possibly related to the agate deposits directly to the south on the opposite side of the rann in eastern Kutch. Although no prehistoric sites are reported in the immediate vicinity of Nagar Parker (to my knowledge, no survey has yet been conducted there), toward the west a number of Indus Civilization settlements (Baloch 1973), including Kot Kori (Khan 1979), have been identified in the southern part of Sindh.

In the northern part of the Sindh Kohistan's Laki Range – a north-south running chain of hills that forms part of the western boundary of the Indus Valley, W.T. Blanford first reported (1869: 5-6) "trap" rock that is "slightly amygdaloidal and contains agates." He later identified these thin, weathered beds of basalt and volcanic tuff as distant outliers of the Deccan Traps (1879: 36-37). Unfortunately, like many geologists then and now, Blanford did not see fit to describe in detail the appearance (size or color) of the actual agate nodules/amygdales within them and no description has since been published. Nevertheless, this occurrence should be regarded as an important potential source due of its correlation to the Deccan Traps and because of its close proximity to a number of Early Harappan and Indus Civilization settlements including Amri (≈ 10 km east), Ghazi Shah (≈ 45 km northwest) and Chanhu-daro (≈ 40 km east). Agate beadmaking was a major industry at Chanhu-daro (Mackay 1938: 52; Sher and Vidale 1985) and a few examples of "chalcedony" were among stone tools debris recovered at Amri (Cleland 1977: 84).

Most ornament-quality microcrystalline silicates in areas of Balochistan adjacent to the Indus Valley are red, green and variegated jaspers associated with ophiolite sequences, such as those in the Zhob and Las Bela districts (*personal observations*). Translucent and semi-translucent varieties do sometimes occur, however. Charles Masson noted (1844: 463) that "agates ... are found in the hills east of Kalat" in central Balochistan but he did not describe them. Although some such stones from this area might have found their way down to Indus Tradition peoples at plains sites like Mehrgarh and Nausharo (≈ 100 km to the west-northwest), they probably were not of especially good quality.

Agates occurring in western Balochistan's Chagai District are a different story. Excellent quality

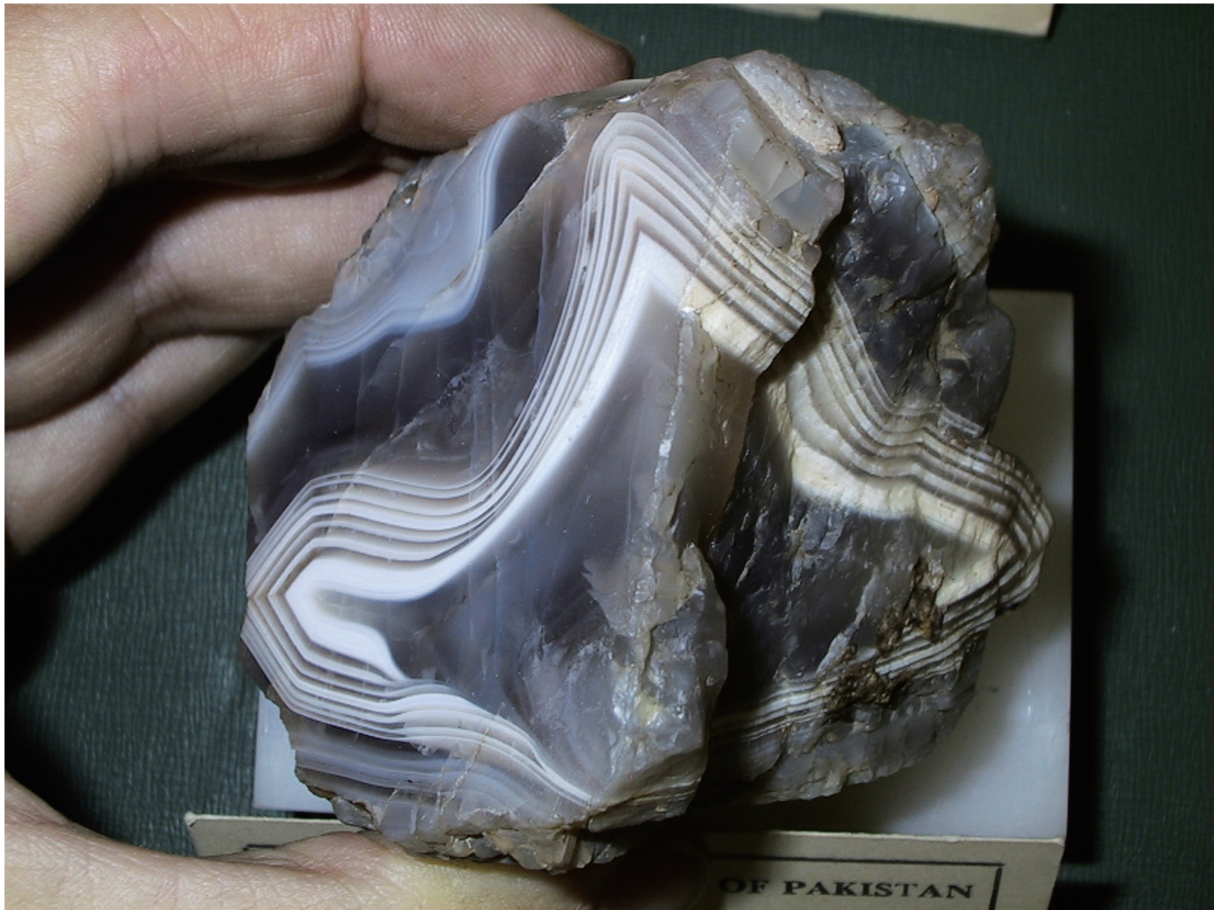



**Figure 8.24** Brown and white banded agate from Taftan railway station, Chagai District, Balochistan. GSP-Quetta Museum, Case 41.

examples can be found within and eroding from the andesitic lavas of the region's volcanic formations. Of these agates, Heron [Crookshank] wrote (1954: 131) that "they are as good as the similar stones from Broach [Ratanpur], India, and ... often display novel patterns not found among the Indian stones." An example of one – collected near Taftan railway station and now on display at the Geological Survey of Pakistan's museum in Quetta, can be seen in Figure 8.9. Others are reported at the extinct volcano known as Koh-i-Sultan (Iqbal *et al.* 1993) and in the desert 45 miles (72 km) west of Nokundi (Heron [Crookshank] 1954: 131). These agate sources are particularly important because of their proximity to the rich copper deposits and ancient smelting areas of the Chagai District and the adjacent Gardan Reg region of southwestern Afghanistan (Dales 1992; Vredenburg 1901). Analyses conducted for this study indicate that some copper ore fragments at Harappa likely came from sources located to the west of the Indus Valley (see Chapter 12). If those western sources happened to be in the Chagai District (this is not yet demonstrated but it is a distinct possibility) then agates from the area might have been acquired as well.

***Agate deposits beyond the Greater Indus region***

In this final section, I provide a brief overview of agate occurrences in Afghanistan, Central Asia, Iran and Arabia – lands outside of the Greater Indus Region with which Harappans had demonstrated contacts (see p. 47).

There is not a great deal of published information regarding the agate occurrences of Afghanistan. In their review of the natural resources of Mundigak – a Bronze Age settlement in the southern part of

that country, Jarrige and Tosi mentioned (1981: 137) that various kinds of microcrystalline silicates "are available in the talus slopes of the Hindu Kush in form of pebbles of different sizes." Closer sources were available to the residents of that site, however. Just 45 km to the southeast, C.L. Griesbach reported (1881: 52, 59) amygdales filled with agate and carnelian in the volcanic trap rock around Kandahar city.

Agate sources in Central Asia, although remote, bear mentioning here because of the clear contacts that Harappans had with BMAC peoples, both in the southern part of that region (Hiebert 1995) and in the Indus Valley (Parpola 2005). Gem quality chalcedony is reportedly found in the Turkestan Range of Uzbekistan (Clarke 1970: 534) and agates are mined today in Tajikistan (Nokleberg *et al*. 2005: 78). Rich deposits also occur in the Irtysh and Pavlador regions of Kazakhstan (Bryksina *et al*. 2001; Yerofeyev and Matsui 1986).

Moving now to sources in Iran, Whitehouse noted (1975: 130) that "nodules of red and orange carnelian erode out of Tertiary sediments" on the Bushehr Peninsula. This occurrence's location adjacent to the Persian Gulf might have made it an important source for consumers in ancient Mesopotamia. However, the "most celebrated Iranian agate localities are in the central and eastern" part of the country (Nazari 2004: 21). Around the Khur area, primary context banded agate nodules occur within tuffaceous andesite (ibid.). Extensive secondary context deposits can be found in Iran's broad salt deserts (dasht) and inland deltas. The explorer Henry Savage Landor marveled (1902: 79) at the "handsome agates" and other colorful stones spread across the wastes of the Dasht-e Lut. Hakemi wrote (1997: 15) that "carnelian is found in considerable quantities in the Lut flood plain." Finally, Tosi noted (1969: 374) that "with regard to cornelian ... numbers of little pebbles of this stone, with a diameter often exceeding 3 cm, may be collected along the dried out beds and ancient branches" of the Helmand River delta near the site of Shahr-i-Sokhta.

Lastly, at al-Ghail, near the northern tip of eastern Arabia's Oman Peninsula, Burkhart Vogt reported (1996: 112) that at outcrops bearing "clear traces of opencast mining and quarrying ... banded agate and carnelian of different varieties and qualities appear in thick veins and are easily accessible." Although it may seem unlikely that raw material from this distant source was shipped all the way to bead workshops in the Indus Valley, Harappans did have a significant presence in this region and so the possibility cannot be completely ruled out. Agate-carnelian occurrences can also be found in central Yeman (Overstreet *et al*. 1985: 319). However, there is no evidence, at present, that Harappan interaction networks in Arabia extended that far to the south.

#### Section conclucion

There are several reasons why it was necessary to provide a full overview of agate occurrences in the Greater Indus region and beyond even though only three of the deposits discussed above were actually sampled and analyzed. Firstly, it allows the provenience study that follows to be put into perspective. Although the results of this study bode well for future research of this kind, it was important to make clear that they are based on the analysis of only a limited number of potential sources. Secondly, the overview will aid in the interpretation of the study's results. We will see that while most of the agate artifacts analyzed seem to be closely related to the one of the sources in the geologic dataset (described at the beginning of the next section), there are a handful that clearly do not. The possible provenience of those standouts can be better judged now that a broad picture of occurrences has been presented. Lastly, it needed to be shown (insofar as the published information made it possible) that all agate deposits are not the same. Like so many of the other materials examined for this study, the appearance, size and quality of microcrystalline resources vary considerably

from occurrence to occurrence. Just because "agate" is reported at a particular locality does not mean that stone that Harappan beadmakers would have found suitable occurred there.

## A GEOLOGIC PROVENIENCE STUDY OF AGATE ARTIFACTS FROM HARAPPA AND FIVE OTHER SITES

In this half of the chapter, I recount how agate artifacts from Harappa and five other Indus Tradition sites were analyzed (using INAA) and compared (using CDA) to samples from three sources in Gujarat and a set of artifacts from the site of Shahr-i-Sokhta that were treated as proxy samples for sources in eastern Iran. The main objective was to evaluate the widely held assumption that Harappan agate primarily came from Gujarat and that the principal sources within that state were the Ratanpur area deposits. Noting the agate occurrences at Mardak Bet and in eastern Kutch, Ratnagar had asked (2004: 146) "did the Harappan inhabitants of Dholavira know of these sources?" This was a good question. Seemingly, those agate occurrences should have been far more accessible to the Harappans of that city than the Ratanpur area deposits, which are located hundreds of kilometers to the southeast (recall Figure 8.6). Although no artifacts from Dholavira were available for this study, it was reasoned that if Gujarat was the principal region from which Indus Civilization peoples obtained agate resources, then it should be possible to indirectly address Ratnagar's question through provenience analyses of artifacts from other Harappan sites in northern Gujarat and the Indus Valley proper. Before detailing and interpreting the results of this study, the selection of source (and proxy source) samples for the geologic dataset are discussed and the agate artifacts that were analyzed are introduced.

### Agate source and proxy source samples

For this study, agate samples were collected from the three potential sources in Gujarat – Mardak Bet (source code = GMB, Figure 8.25), Khandek (GKK, Figure 8.26) and Ratanpur (GRTP, Figure 8.27). Although material-wise, each of these secondary context deposits is extremely variable, the samples selected for analysis represent a narrow range of types. Most (but not all) are either natural carnelian or the type of yellowish-brown, iron-impregnated agate that will develop the red-orange hue characteristic of carnelian when heat-treated. Twenty samples from each source were selected (note that only 12 of the 20 from GMB and GKK are actually pictured on figures 8.26 and 8.27 respectively). Earlier I described how agates collected from across a three kilometer-long zone at Ratanpur were treated as coming from a single source. The same will be the case for all samples acquired at GMB (even though the set contains agate from both "nana" and "mota" Mardak Bet) and GKK.

I was unable to visit any agate occurrences other than the three just discussed, which was unfortunate as it would have greatly benefited this study to include samples from a geologic source outside of Gujarat for comparison. A solution to this problem was provided by Dr. Massimo Vidale (l'Istituto Italiano per l'Africa e l'Oriente [IsIAO], Rome) when he generously granted me access to agate manufacturing debris he had collected from the surface of Shahr-i-Sokhta – a Bronze Age urban center in eastern Iran (Tosi 1982). These artifacts, which consisted of chunks of both variegated agate-carnelian and bluish-hued chalcedony (Figure 8.28), were, in all likelihood, derived from known occurrences (described in the previous section) near that site or in the general region. The decision was made to use the debris fragments as proxy samples for a "source" (source code S-i-S) in eastern Iran. It is recognized that the 14 samples selected might not be from the same locality and that some samples, potentially all of them, might not even be from a source in Iran. Nevertheless,




**Figure 8.25** Agate samples from Ratanpur, Gujarat (source code = GRTP).




**Figure 8.26** Agate samples from Khandek, Gujarat (source code = GKK).

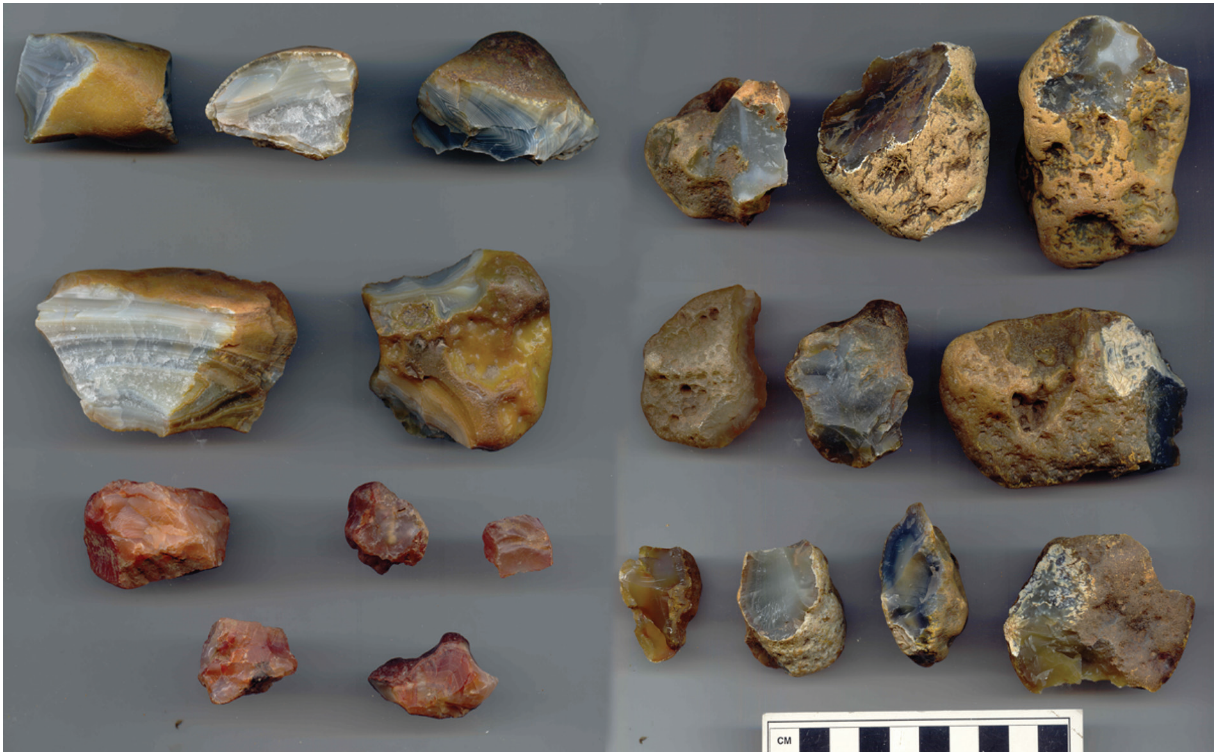



**Figure 8.27** Agate samples Ratanpur, Gujarat (source code = GRTP).




**Figure 8.28** Archaeological agate fragments from Shahr-i-Sokhta, Iran (source code = S-i-S).

with those qualifications, they were included in the geologic dataset.

### Agate artifacts

For this study, 24 agate artifacts from Harappa and 32 from five additional Indus Tradition sites were analyzed and compared to the geologic dataset outline above.

#### *Artifacts from Harappa*

The 24 agate artifacts from Harappa that were selected for analysis come from various periods and parts of the site (Figure 8.29). They are numbered AH-1 to AH-24 for this study. Their original HARP numbers and context information are listed in columns two and three of Appendix 8.5. Only 11 of the 24 artifacts were recovered from secure stratified contexts. One comes from Kot Diji Phase levels while the remaining ten come from Harappa Phase levels (three from Period 3B and seven from Period 3C). Nineteen of the 24 artifacts were recovered on mounds E or ET. Of the remaining five, two came from Mound AB and one from a layer of Harappan dump debris in the cemetery area. The exact provenience of two artifacts (AH-1 and AH-2) is unclear. They are agate-chalcedony nodule fragments (Figure 8.30) from pre-HARP excavations that had been stored in the Harappa Museum's Reserve Collection of large stone objects. In fact, these are the two biggest agate artifacts yet recovered at Harappa (AH-1 weighs approximately 0.7 kg and AH-2 weights around 4 kg). Given that they are from the excavations of the 1920s and 30s, it is most probable that they come from Harappa Phase levels either on Mound AB or F.

The set of agate artifacts from Harappa (Figure

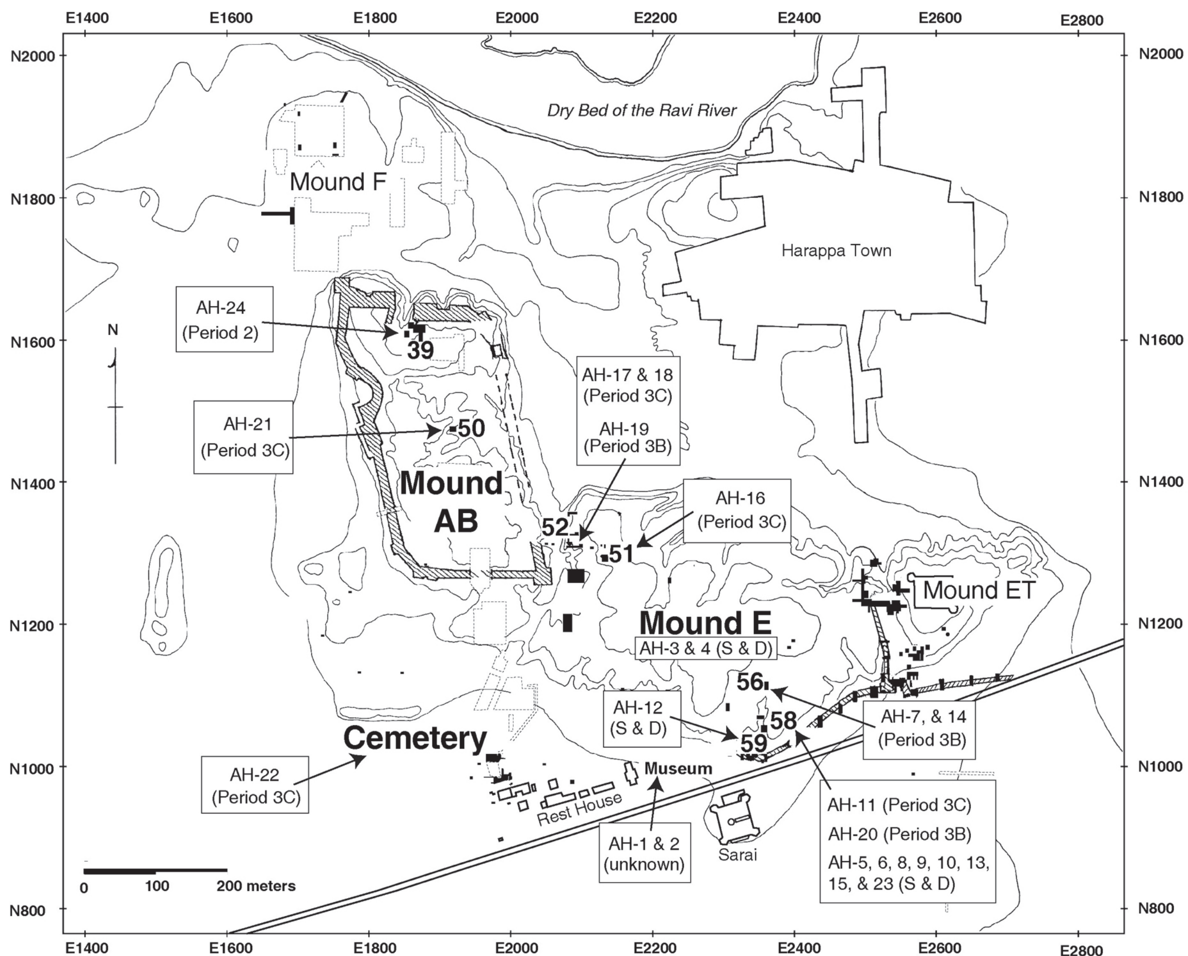



**Figure 8.29** Spatial and period-wise distribution of analyzed agate artifacts from Harappa.

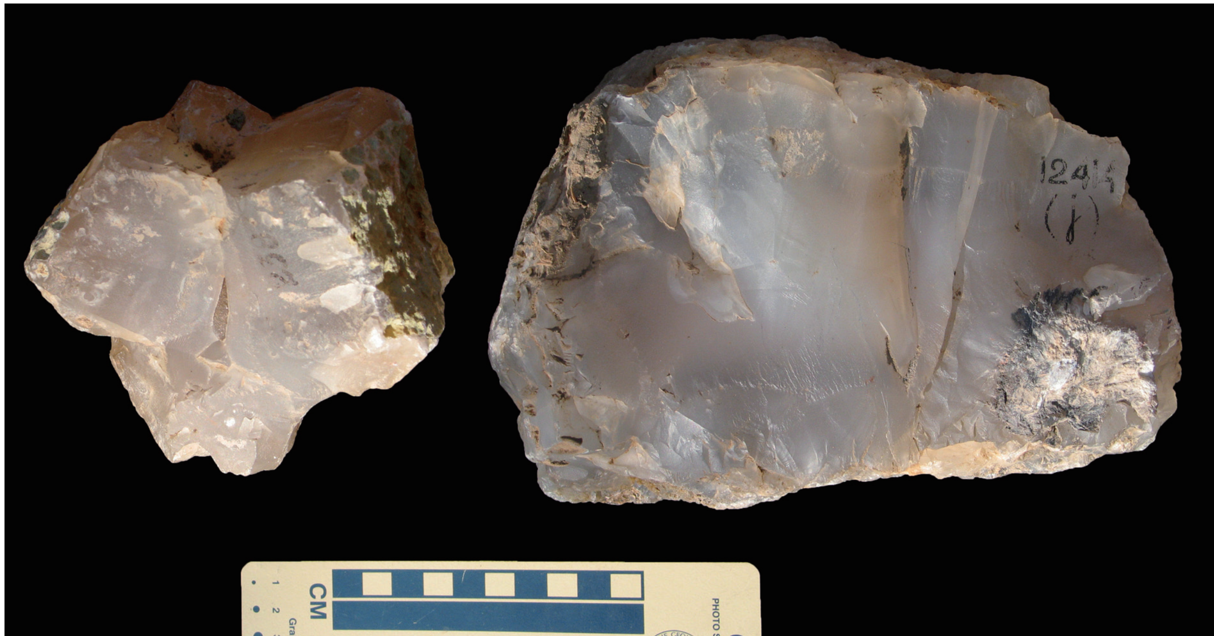



**Figure 8.30** Two large agate nodule fragments from previous excavations at Harappa analyzed for this study. Left – HM 2397 (AH-1). Right – HM 12414 (AH-2)

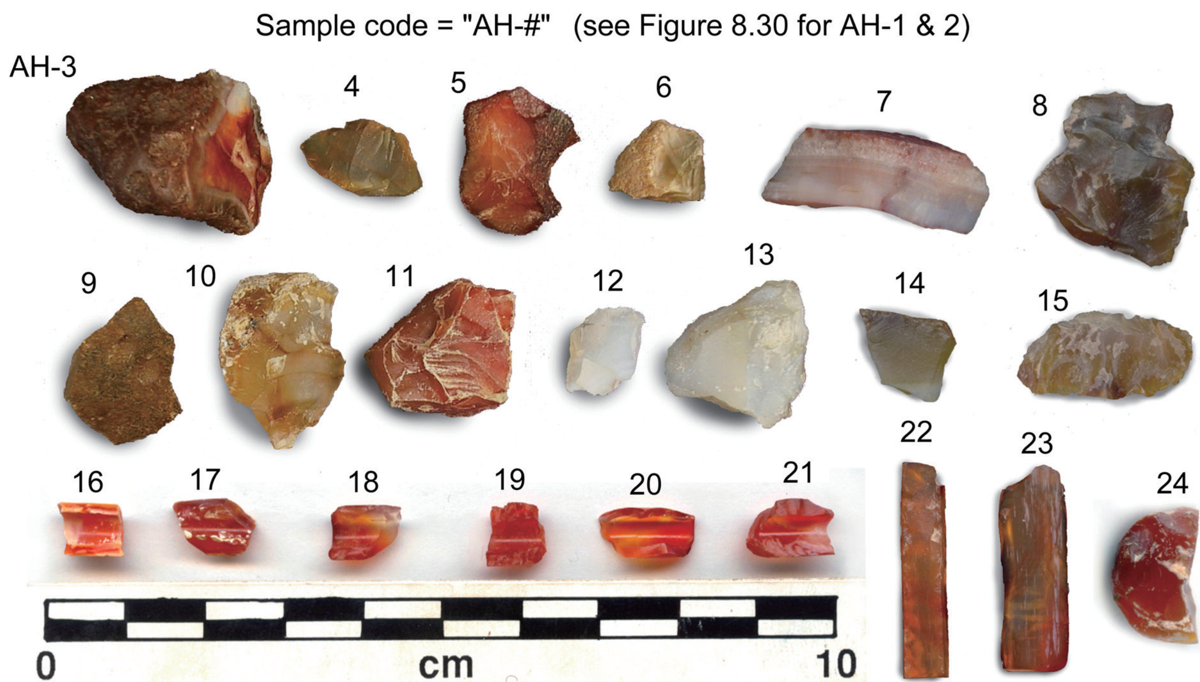



**Figure 8.31** The remaining agate artifacts from Harappa analyzed for this study.

8.31) includes thirteen nodule fragments or flakes (AH-3 to AH 15) in addition to the chalcedony nodules just discussed. Examples of carnelian, yellowish-brown agate and semi-translucent chalcedony were selected. I have observed each of these types at all three of the potential sources in Gujarat.

The remaining items in the Harappa agate artifact dataset are all bead fragments. Eight are broken pieces of classic Harappan-style long-barrel carnelian beads (AH-16 to AH 23). A complete example (which was not analyzed) is provided on the figure for comparison. Because this style of bead was only manufactured during the latter half of the Harappa Phase (J. Mark Kenoyer *personal communication* 2007), it is possible to say that the one example (AH-

23) that was recovered from a non-secure context is very likely from either Period 3B or 3C. Importantly, agate-carnelian nodules large enough to make these long beads are rare. The little (≈ 3 cm) carnelian pebbles Tosi described (1969: 374) near Shahr-i-Sokhta would have definitely been too small. Nodules of sufficient size are known mainly to occur in Gujarat at Ratanpur, Kapadvanj and Mardak Bet (Trivedi 1963: 9-11). Although I did not observe any nodules bigger than about 7 cm at Khandek in eastern Kutch, in all likelihood any larger ones that had once been on the surface there were gathered up long ago.

A fragment of a circular-shaped carnelian bead (AH-24) from Period 2 levels on Mound AB rounds out the Harappa agate artifact set.

*Artifacts from five other Indus Tradition sites*

In addition to the proxy source samples from Shahr-i-Sokhta, Massimo Vidale kindly provided agate debris fragments related to his work on craft activity areas at the sites of Mohenjo-daro (Vidale 1987a) and Chanhu-daro (Sher and Vidale 1985) in Sindh. The seven artifacts from Mohenjo-daro (Figure 8.32 A) were collected from among lapidary debris on the surface of the "Moneer" area and include examples of yellowish-brown agate, banded carnelian and chalcedony. Although it impossible to say with certainty, this debris probably dates to the latter part of the site's Harappa Phase occupation. The seven artifacts from Chanhu-daro (Figure 8.32 B) closely resemble those from Mohenjo-daro and, although they are from the site's surface, also likely date to the Harappa Phase.

Dr. Kuldeep Bhan (Department of Archaeology, Maharaja Sayajirao University, Baroda) generously provided three yellow-brown agate flakes (Figure 8.32




**Figure 8.32** Agate artifacts from five Indus Tradition sites analyzed for this study.

C) recovered in Harappan Period levels at Nagwada in northern Gujarat. Importantly, this site is located just east of the Little Rann of Kutch around 60 km from the agate source at Mardak Bet.

Finally, Jean-François and Catherine Jarrige (Centre de Recherches Archéologiques Indus-Balochistan, Asie Centrale et Orientale at the Musée Guimet Paris), graciously provided a set of eight agate fragments (Figure 8.32 D) from the site of Mehrgarh. Seven are plain or banded chalcedony and one is carnelian. All are surface finds from the site's MR2 area, which would date them to Mehrgarh Period III (ca. 4800-3500 BC). The Jarriges also supplied seven broken carnelian beads (Figure 8.32 E) from their excavations at nearby Nausharo. Three come from levels (Period 1C and 1C/1D) around the site's Early Harappan-to-Harappan Phase transition (Jarrige 1993) while four are from Harappan Phase levels (Period III – ca. Period 3B at Harappa). The Mehrgarh and Nausharo artifacts are of particular interest because of those sites' location the foot of the Bolan Pass – a major route into the highlands of Balochistan and beyond to the Helmand Basin. People living there would have been well-placed to acquire agate from sources to the west of the Indus Valley.

### Analysis and comparison

The sets of agate artifacts and geologic source samples introduced above were subjected to instrumental neutron activation analysis (INAA) following sample preparation and irradiation procedures outlined in Chapter 3. Out of the data that were returned, ten elements (Al, Co, Cr, Eu, Fe, La, Na, Sb, Sc and V) free of missing values were selected for use in comparisons of the two sets using canonical discriminant analysis (CDA). The measured concentrations of those elements in the source samples and artifacts are listed in the following appendices: GRTP = Appendix 8.1; GMB = Appendix 8.2; GKK = Appendix 8.3; S-i-S = Appendix 8.4; Harappa artifacts = Appendix 8.5; Mehrgarh and Nausharo artifacts = Appendix 8.6; Mohenjo-daro, Chanhu-daro and Nagwada = Appendix 8.7. In Appendix 8.9, the standardized (canonical) discriminant function coefficients for each of the figures in this chapter generated using CDA (figures 8.33 through 8.36) are listed.

First, the GMB, GKK, GRTP source and S-i-S proxy source samples were compared to one another as four sets of grouped cases (Figure 8.33). Good separation between the source-groups resulted. Exactly 85.1% of leave-one-out cross-validated grouped geologic cases were classified correctly. Most of the misclassification (overlap) that occurred was among the three Gujarati agate sources. Only one sample from S-i-S (noted on Figure 8.33) was misclassified as belonging to a Gujarati source (Mardak Bet) when it was cross-validated. That particular fragment – S-i-S_14 (Figure 8.28, *bottom row, fourth from the left*), is a piece of milky, semi-translucent chalcedony that is unlike the other samples (both the variegated agate-carnelians and the bluish-chalcedonies). Overall, however, it can be said that the Iranian agates are quite distinct from the Gujarati sources.

Next, the agate artifacts from Harappa and the five other sites were compared to the grouped geologic sources and plotted as ungrouped cases in relation to them (Figure 8.34). The first predicted group memberships (PGMs) for all of the artifacts are listed in the column labeled *Figure 8.34* in Appendix 8.8. In total, nine of the 56 artifacts had a first PGM in the S-i-S proxy source-group. Each of those nine are labeled on Figure 8.34. Four of them were from Harappa (AH-1, 2, 9 and 20), two were from Chanhu-daro (ACD-3 and 4), two were from Nausharo (ANS-5 and 6) and one was from Mehrgarh (AMR-2). The remaining 47 agate artifacts were assigned a first PGM in one of the three sources in Gujarat. Twenty-six of those had a PGM in the Mardak Bet source-group and 16 had a PGM in the Khandek source-group. Only five agate artifacts had a PGM in the Ratanpur

source-group. Two of these were from Harappa (AH-14 and 22) and one each was from Nagwada (ANG-1), Mehrgarh (AMR-8) and Nausharo (ANS-4).

The results of the initial CDA indicate that majority of the artifacts analyzed from Harappa and the other sites are geochemically more analogous to agate from sources in Gujarat than they are to agate artifacts from Shahr-i-Sokhta, which are presumably from a source(s) in the general vicinity of that site in eastern Iran. Furthermore, the majority of those artifacts predicted to belong to one of the Gujarati sources are more closely related to agate samples from Mardak Bet and Khandek in northern Gujarat than they are to samples from the Ratanpur area in the southeastern part of that state. However, rather than making interpretations based upon these initial results, two additional CDAs were conducted in an effort to 1) achieve better discrimination between the Gujarati sources and the S-i-S group and 2) achieve better discrimination between the three Gujarati sources themselves.

In order to achieve better statistical separation between agate samples from Gujarat and agate artifacts (presumably) from Iran, the cases that make up GMB, GKK and GRTP were combined into a single group that was designated "Gujarati sources." This new source-group was then compared to the S-i-S proxy source-group using CDA. Because only one discrimant score (function) is generated when two groups of cases are compared to one another, it is not possible to make a bivariate plot of the results. An excellent way to display univariate data of this kind is by using a *box plot* (sometimes called a box-and-whisker diagram). For the box plots shown on the next page (Figure 8.35), the two sets of grouped cases ("Gujarati sources" and S-i-S) and the ungrouped cases (agate artifacts from Harappa and the other sites) were plotted on a horizontal axis based on their first (and in this case only) discriminant scores. The distribution of the case data making up each group-source is divided into quartiles with the gray boxed areas depicting the second quartile, which encompasses the middle 50% of the cases. The range demarcated by the "whiskers" that extend from the left and right of the box depict the lower and upper 25% of the case data (the first and third quartiles respectively). The median of the grouped cases is depicted as a line dividing the second quartile box and individual cases that are outliers of the main group of cases are plotted apart as small circles. For more detailed information regarding the generation and utility of box plots see Shennan (1997: 45-46) or Benjamini (1988).

Excellent (although still not perfect) separation between the Gujarati sources group and the S-i-S group was achieved. Precisely 95.9% of leave-one-out cross-validated grouped cases were classified correctly. Proxy source sample S-i-S_14 (the labeled outlier of the S-i-S box plot in Figure 8.35) was again misclassified as belonging to a Gujarati source. Two samples from the Gujarati source-group (GMB-13 and GKK-14) were misclassified as belonging to the S-i-S group. By and large, however, the two source-groups are very distinct from one another as is evident from their box plots on Figure 8.35. Dashed lines were drawn to indicate the upper limit of the Gujarati sources' third quartile and the lower limit of the S-i-S group's first quartile (which does not include the outlier). The artifacts from Harappa and the five other sites are plotted below the box plots of the two source-groups using small vertical bars. A thin line connects each bar to a label on the left side of the plot that indicates the number of the artifact it represents. The PGMs for all of the artifacts are listed in the column labeled *Figure 8.35* in Appendix 8.8. In this CDA, the PGM of eleven artifacts was in the S-i-S group. Each of these is identified on the figure by an asterisk next to its label. They include the exact same nine predicted to belong to the S-i-S group in the previous CDA (Figure 8.34) plus AMD-2 and AH-13.

The results of this CDA once again indicate that the large majority of the artifacts analyzed are more

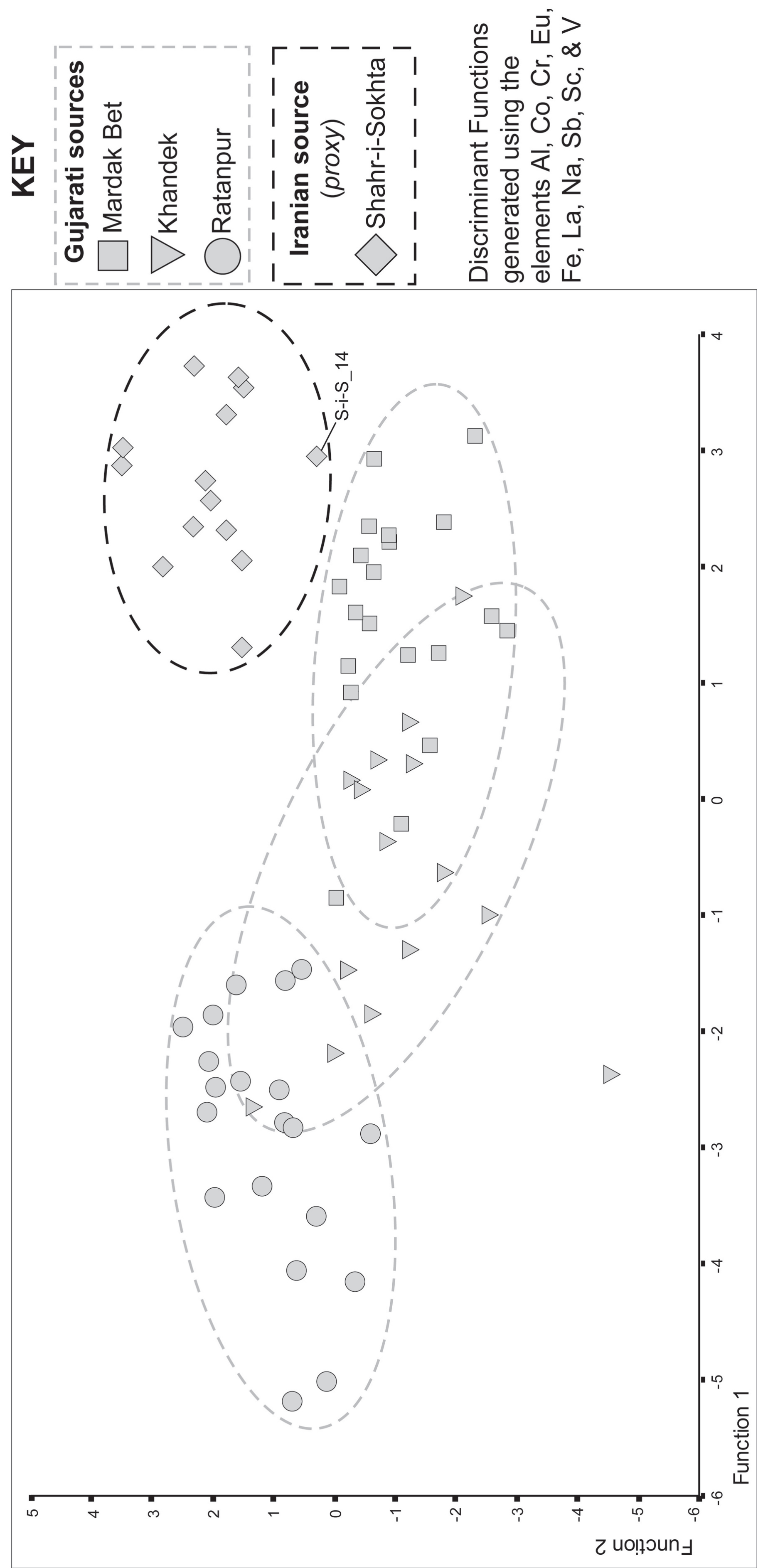



**Figure 8.33** CDA comparison of Gujarati and Iranian (proxy) agate sources.

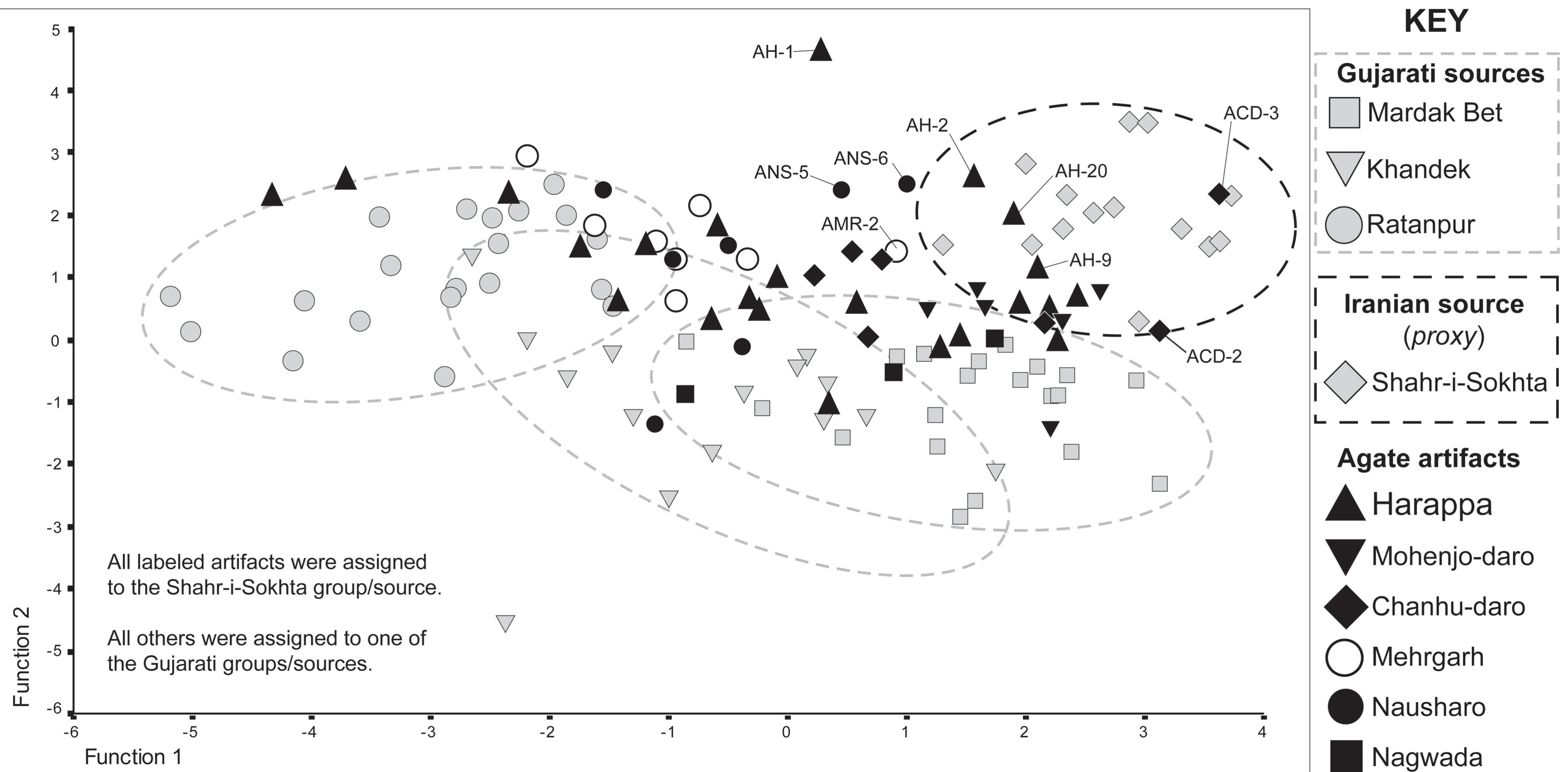



**Figure 8.34** CDA comparison of agate artifacts to Gujarati and Iranian agate sources.

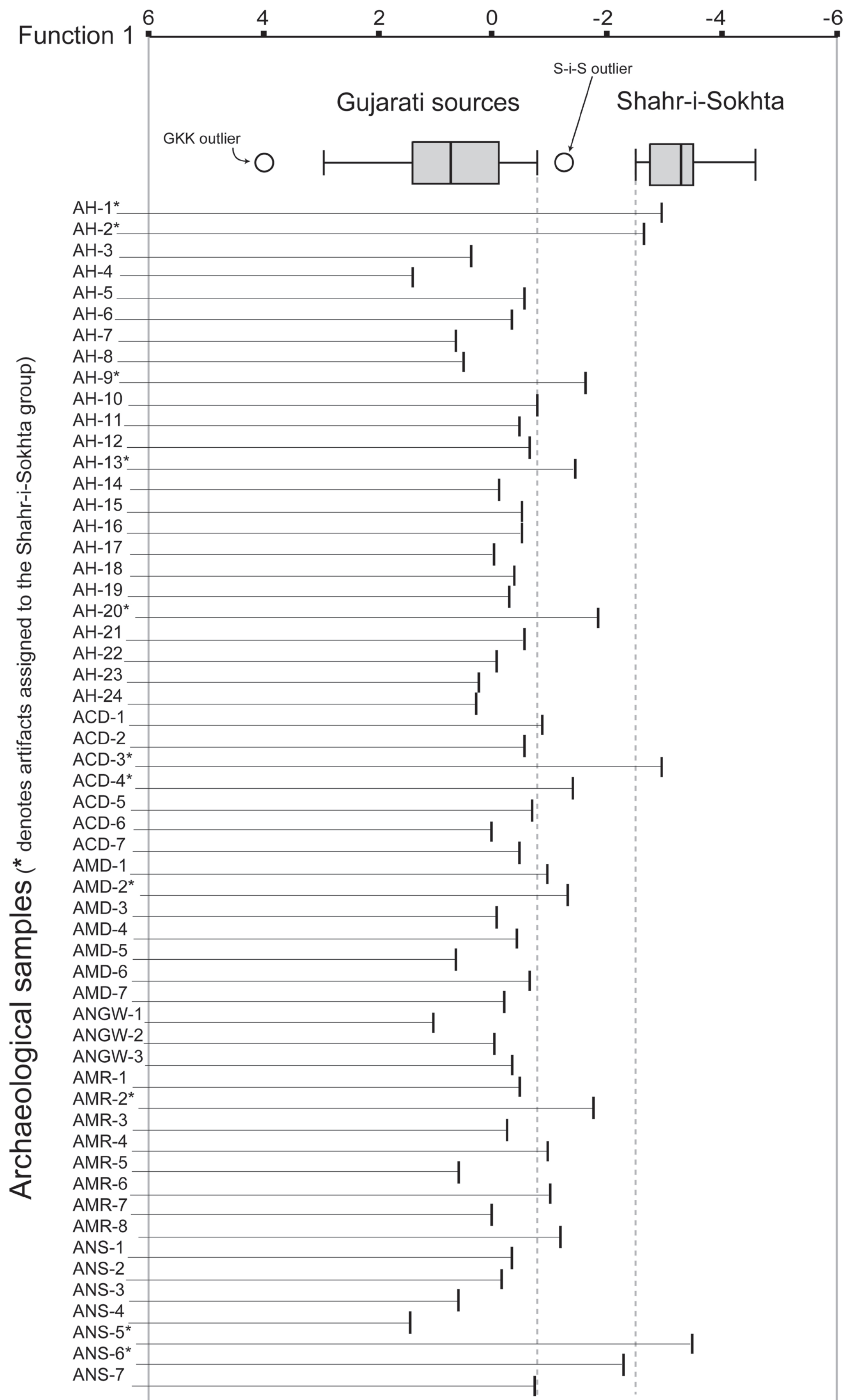



**Figure 8.35** Gujarati agate sources compared as one group to the Shahr-i-Sokhta agates. Box plots generated and artifact points plotted using the CDA first discriminant function.

closely related to agate samples from sources in Gujarat than they are to artifacts/proxy source samples from Shahr-i-Sokhta. Note, however, that a number those that were assigned to the Gujarati source-group (AMR-4, 6 and 8, AMD-1 and ACD-1) lie above the upper limit of its third quartile while many of those assigned to S-i-S (AH-9, 13 and 20, ACD-4, AMD-2, AMR-2, ANS-6) plot below the lower limit of its first quartile. Such artifacts could genuinely be outliers of the source-group to which they were assigned. Alternately, they could be misclassified outliers of the opposite source-group. They could (and so could any other artifact in the set regardless of where it plotted) also be from a source not analyzed and simply assigned to the one in the set they more closely resembled.

For the final CDA, the three agate sources in Gujarat (GMB, GKK and GRTP) were compared to one another alone, without the S-i-S proxy source-group (Figure 8.36 A). Although good separation between the three was achieved, it was only slightly better than that for the original CDA (Figure 8.34). Exactly 86.7% of leave-one-out cross-validated grouped cases were classified correctly this time whereas 85.1% were classified correctly when the S-i-S source-group was included in the analysis. This indicates that nearly all of the overlap (misclassification of grouped cases) in the dataset is among Gujarati sources rather than between them and the Iranian artifact/proxy source samples. In this instance, the misclassifications were among the GMB samples (one was predicted to belong to GRTP) and the GRTP samples (one was predicted to belong to GMB and three to GKK).

On Figure 8.36 B, the 45 artifacts that had *not* been predicted to belong to the S-i-S proxy source-group in one of the previous CDAs are plotted as ungrouped cases in relation to the three Gujarati source-groups. The PGMs for each of those are listed in the column that is labeled *Figure 8.36* in Appendix 8.8. In this CDA, 27 artifacts were predicted to belong to GMB, 14 to GKK and four to GRTP. For the most part, these PGM assignments are unchanged from the first CDA (compare them to column labeled *Figure 8.34* in Appendix 8.8). Two artifacts that had been assigned to GMB now had a PGM in GKK and one that had been assigned to GRTP was now predicted to belong in GMB.

The results of this CDA serve to confirm what was evident in the initial one – that the majority of those agate artifacts assigned to a Gujarati source more closely resemble samples collected from Mardak Bet and Khandek than they do samples from Ratanpur. Before commencing with the interpretation of all the results in the next section, it should be noted that there are a number of artifacts that, while assigned to Gujarati sources in the first two CDAs, now plot apart from the three source-groups in Figure 8.36 B suggesting that they are somewhat distinct from them. Dashed ellipses (these and the ones on the other figures in this chapter are visual guides and not any form of confidence interval) have been drawn around the source groups and a few of the more distant outliers have been labeled. These artifacts might merely be outliers of the sources to which they are assigned. However, they could be from a different source in Gujarat or even from a source outside of that region. It is for this reason that caution is advised. The geologic data set that the artifacts are being compared is not necessarily representative of all of the potential sources to which Indus Tradition might have had access. Any interpretation of the results must recognize this element of uncertainty and include the appropriate qualifications.

## Interpretation (and qualification) of the results

If the results of this study are taken at face value – i.e., without questioning any of the PGMs made during the CDAs presented above, then the following statements can be made: It appears that Indus Tradition peoples at the sites of Harappa, Mohenjo-

daro, Chanhu-daro, Nausharo, Mehrgarh and Nagwada acquired the majority of their agate from the Gujarat region. Most of it came from sources located in the northern part of that state rather than from the Ratanpur area, as is often assumed. There are some indications that Early Harappans and/or Harappans at all of the sites examined (except for Nagwada) may have also utilized some agate from sources other than the three in Gujarat that were analyzed. Some of those sources were probably located elsewhere in Gujarat while others may have been in regions to the west of the Indus Valley. Although this interpretation is, more or less, the same as that presented in the provisional conclusion for this chapter, there are multiple aspects of it that require qualification.

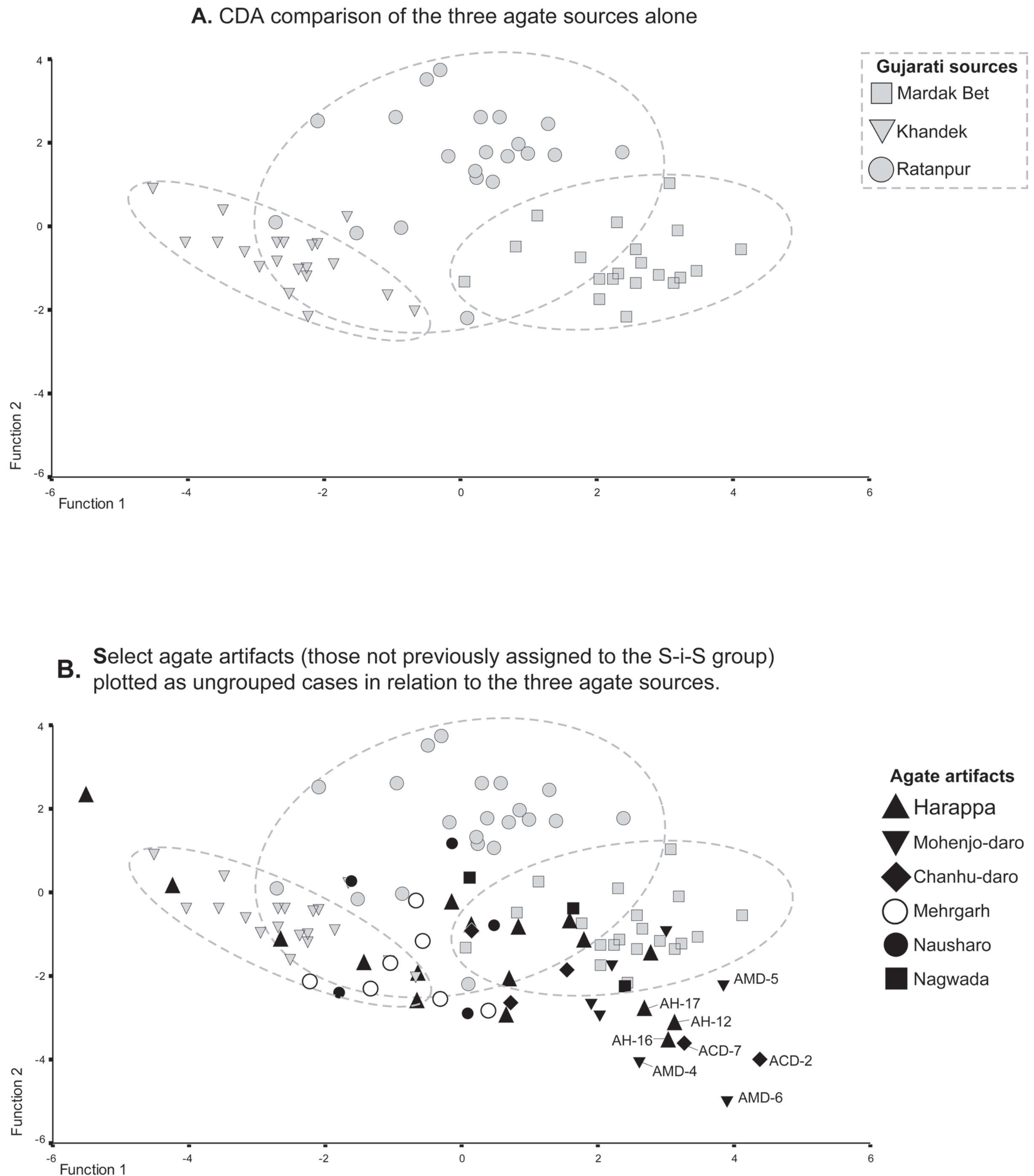
***Artifacts from Harappa***

First of all, consider the five agate artifacts from Harappa that were predicted in the first and/or second CDAs to belong to the S-i-S proxy source-group. Included among them are the two large agate-chalcedony nodule fragments (AH-1 and 2) pictured in Figure 8.30. These were the only two that actually plotted among the spread of discriminant scores that make up the box plot for S-i-S on Figure 8.35. Assuming that the Shahr-i-Sokhta artifacts did not come from a source in Gujarat (or from a geochemically related source elsewhere in the Deccan Traps) then it is reasonable to assume that the two nodules likewise did not come from that region. I am, however, reluctant to firmly declare that they are from a source in eastern Iran. They are obviously very different in size and appearance from those Tosi described in the vicinity of Shahr-i-Sokhta. They might instead have come from occurrences in southern Afghanistan or western Balochistan. Or they might be from a source in an altogether different region. Still, geochemically, the nodules do resemble the S-i-S artifacts far more than they do the geologic samples from sources in Gujarat. Therefore, it is provisionally concluded that Harappans likely acquired them from an agate occurrence(s) to the west of the Indus Valley, perhaps one in the Helmand Basin region.

The remaining three artifacts from Harappa (AH-9, 13 and 20) that were predicted to belong to the S-i-S source-group plotted in the gap between that group's first quartile and the Gujarati sources group's third quartile. For this reason, I am even more reluctant to than I was with AH-1 and 2 to accept their PGMs; that is, at least not without first making a few qualifying statements. These artifacts could well be outliers of the Gujarat Mardak Bet source that just happened to plot nearer to the centroid of the S-i-S source-group. AH-13 was actually assigned to GMB in the initial CDA (see Appendix 8.8). It is also possible that the three are from unsampled agate deposits in Gujarat (such as those in central Kutch or the ones in the Kapadvanj area) that happen to have trace element characteristics slightly more like those of the source(s) from which the Shahr-i-Sokhta artifacts were acquired (wherever that might be). Furthermore, it should be noted that AH-20 is a fragment of a carnelian long bead. The large-sized iron-impregnated nodules required to make those beads are not, at least to my knowledge, found in regions outside of Gujarat or Central/Peninsular India. There might, of course, be sources of such nodules to the west or north of the Indus Valley that have not been reported or described. For that matter, there also may be agate sources in those regions that have trace element characteristics similar to the ones in the Deccan Traps – the Laki Formation trap of Sindh Kohistan is a strong candidate for being one of these. However, until those other potential sources are better described and analyzed it is impossible to do more speculate. Based on limited geologic dataset that was available for comparison, the best that can be said at present is that AH-9, 13 and 20 *may* have been acquired from a source to the west of the Indus Valley.

With regard to the 19 agate artifacts from

**Figure 8.36** CDA comparison of select agate artifacts to three agate sources in Gujarat.




Harappa that were consistently assigned to one of the Gujarati sources, it can be stated that most likely came from a deposit in the northern part of that state (a few possible exceptions – the outliers labeled on Figure 8.36 B, are discussed below). When the three Gujarati sources analyzed were compared only to one another (Figure 8.36), just a single artifact (long bead fragment AH-22) was assigned to the Ratanpur source. Of course, the cross validation success rate for that CDA was 86.7%, which means that some of the artifacts assigned to GMB and GKK might have actually be misassigned outliers of GRTP. On the other hand, AH-22 could just as easily be a misassigned outlier of GMB, which was its second PGM. I favor the latter possibility given the fact that 11 of the 19 agate artifacts were predicted to belong to the GMB source.

One chalcedony fragment (AH-12) and two broken carnelian long beads (AH-16 and 17) from

Harappa are among the handful of agate artifacts (labeled on Figure 8.36 B) that in the third CDA plotted markedly apart from the three Gujarat source-groups. It is possible that some or all of these distinct artifacts are outliers of GMB – the source to which all were assigned. Characterization of additional geologic samples could expand the spread of cases making up that source-group enough to encompass them. On the other hand, the distinctiveness of the artifacts may be an indication that they are from a different source(s). Although that other source(s) could be outside of Gujarat, in the case of the long beads at least, I would argue (for the reason discussed on the preceding page) that it is probably located somewhere within that state. However, until other potential agate sources in Gujarat are sampled and analyzed, the current PGMs of these distinct artifacts will stand.

***Artifacts from the five other Indus Tradition sites***

The PGMs generated for the artifacts from Nagwada are fairly straightforward. It appears that the Harappans of that site were, not surprisingly, acquiring agate from sources in Gujarat. Two fragments were assigned to the relatively nearby occurrence at Mardak Bet while one was predicted to come from the Ratanpur source. With regard to artifacts analyzed from the four other Indus Tradition sites, a few qualifying remarks are required.

All but one of the Mohenjo-daro artifacts analyzed were predicted to belong to the GMB source. The single fragment (MD-2) from that site that was assigned to the S-i-S group in the second CDA (Figure 8.35) is likely a misassigned GMB outlier. Most of the Chanhu-daro artifacts were also predicted to belong to GMB. Of the two from that site that were assigned to the S-i-S proxy source-group, one (ACD-4) is perhaps a misassigned GMB outlier. The other (ACD-3) is distinct enough (see it plotted on figures 8.34 and 8.35) to suggest that it is probably from a source outside of Gujarat. As was the case with the two large chalcedony nodules from Harappa discussed at the beginning of this section, that source could be in the Helmand Basin region. On the other hand, agate occurs just 40 km west of Chanhu-daro in the trap rock of Sindh Kohistan's Laki Range. If raw material of even marginal quality exists at that location (this is by no means certain) then there is a strong possibility that some of it ended up in the workshops of Chanhu-daro and, for that matter, of Mohenjo-daro and Harappa too. The artifacts from all three of those sites that plotted distinctly apart from the Gujarati sources on Figure 8.36 B might conceivably have come from the Laki Trap. That formation is reportedly a western outlier of the Deccan Traps and so the agate from it might geochemically resemble agate from Gujarat. Or it might not. It is impossible know until samples from that potential source are analyzed.

Most agate artifacts from Mehrgarh and Nausharo were predicted to belong to an occurrence in Gujarat. However, unlike like those from Mohenjo-daro and Chanhu-daro, few were assigned to the Mardak Bet source. ANS-3 was the sole artifact that consistently had a PGM of GMB. AMR-5 and ANS-2 were assigned to that source only in the third CDA. In the first, they had PGMs of GKK and so may be outliers of that source that were subsequently misclassified. If that was the case, then six of the eight artifacts from Mehrgarh and three of the seven from Nausharo may be from GKK. One artifact at each site was assigned to GRTP while one agate fragment from Mehrgarh and two beads from Nausharo were consistently predicted to belong to the S-i-S proxy source-group.

It is curious how the majority of the agate artifacts at Mehrgarh were predicted to belong to the GKK source while most of those at Mohenjo-daro and Chanhu-daro were assigned to GMB. Both of those occurrences are located within 40 km of each other in northern Gujarat. Why would peoples at those distant settlements in Sindh and Balochistan

have almost exclusively utilized raw material from one source over the other? It is quite possible that what appears to be an emphasis on one source is actually the product of a very limited sample. The analysis of a larger number of artifacts from different phases and parts of the sites in question might reveal more heterogeneous patterns of agate source utilization, like that seen at Harappa. Another reason might have to do with the fact that the Mehrgarh artifacts are from an earlier period (ca. 4800-3500 BC) than those of the other Indus Tradition sites examined in this study. Perhaps material from GMB was not being exploited and/or exported during that earlier period. Later, during the Harappan Period (when GMB agate was evidently being used at sites across the Indus Valley), one or two agate artifacts that may be from that source do appear at the nearby site of Nausharo. A final possibility that must be considered is that some or all of the artifacts from Mehrgarh (and possibly Nausharo too) assigned to GKK might not actually be from Gujarat.

Mehrgarh and Nausharo, located as they are at the foot of the Bolan Pass, were the two sites at which I had most expected to see evidence for the utilization of agate from occurrences to the west of the Indus Valley. And, in fact, there are some artifacts (AMR-2, ANS-6 and, in particular, ANS-5) at both that might be from the Helmand Basin region. That many more were predicted to be from sources in Gujarat was not wholly unexpected. After all, residents of Mehrgarh had been acquiring raw materials (lapis lazuli, turquoise and marine shell) from distant regions since that settlement's earliest period (Jarrige 1991b: 41) and Nausharo was a thriving Indus Civilization town (Jarrige 2000). I have, however, doubts about the correctness of the provenience determinations made for many of the artifacts from the former site. It is not only because their PGMs stand in contrast to those of artifacts from Mohenjo-daro and Chanhu-daro (discussed above). It is also because the quality of several artifacts in the group assigned to GKK – in particular the two tiny chalcedony geode fragments (AMR-6 and 7, pictured on 8.32 D), is rather mediocre. Agate of this type occurs at Khandek but it is hard to fathom why someone would have seen fit to transport it approximately 700 km to Mehrgarh when there was much better raw material available at that source and at others in northern Gujarat. It seems more likely that many of the artifacts in question derived from an occurrence nearer to the site, perhaps the one Masson mentioned (1844: 463) "east of Kalat" in central Balochistan or another one like it. There are no published descriptions of agate from that source and until some is collected and analyzed we have no way of knowing if it is geochemically similar to that from GKK. However, if does turn out to be similar then that has important implications. If some or all of the GKK-assigned artifacts from Mehrgarh are actually from an occurrence to the west of the Indus Valley then those at Harappa assigned to that source could be as well. This possibility further underscores the need to regard the results of this study as provisional.

Now that all necessary qualifying remarks have been stated, the conclusions of this study can be presented. The three lines of inquiry outlined in Chapter 1 are not addressed here as the artifacts analyzed from Harappa are not sufficiently representative, either spatially or temporally, to permit this. The results are instead incorporated into the final overview of Harappan rock and mineral acquisition networks in Chapter 13.

## CHAPTER CONCLUSION

The results of this study bode well for future research of this kind. Using INAA and CDA, it was possible to differentiate samples from three agate deposits in Gujarat reasonably well. However, a superb degree of discrimination was achieved when those deposits were compared to a set of

artifacts presumably from sources in eastern Iran. This indicates that it is possible, at the very least, to assign a regional provenience to agate artifacts. The results of a recent follow-up study (Law *et al.* 2011) lend further support to this conclusion. Samples from two deposits in Gujarat – the group of Iranian artifacts and a newly sampled source in Thailand (Ban Khao Mogun) – were analyzed at the Missouri University Research Reactor. An excellent 95.1% cross validation success rate was achieved. Most of what little misclassification there was occurred the among the Gujarati sources rather than between them and the other regional source or proxy-source samples. There is then very good reason to expect that when the geologic dataset is further enlarged to include agate from deposits in Sindh, Balochistan, Afghanistan, Arabia, Tibet and Central Asia it will be possible to differentiate them and assign a regional provenience to artifacts. In the meantime, the results of the present study permit the following *provisional* conclusions to be made regarding Indus Tradition agate acquisition networks:

The majority of the agate artifacts from Harappa and the five other Indus Tradition sites examined in this chapter appear to have come from sources in Gujarat. Residents of Harappa were acquiring material from that region by at least the Kot Diji Phase. Although this conclusion is based solely on the analysis of a single carnelian bead fragment (AH-24) from Period 2 levels, that particular artifact is one of the more analogous to geologic samples from the Mardak Bet occurrence (it was consistently assigned to that source and is not among distinct outliers on 8.36 B). Gujarat was evidently the primary agate source area for residents of Harappa during the latter half of the Harappa Phase. All but one of the ten artifacts from the site that are securely attributable to periods 3B and 3C were predicted to belong to a deposit in that region. Significantly, most of the Gujarati agate used at Harappa and the other sites appears to have come from sources in the Kutch region rather than from, as is widely assumed, the Ratanpur area deposits in the southeastern part of the state. As this book was being finalized, data became available from the analysis of agate artifacts from the Indus cites of Dholavira in northern Gujarat and Rakhigarhi in Haryana. Overall, those results were very consistent with the agate acquisition patterns revealed in this chapter.

There are indications that Indus Tradition peoples sometimes utilized agate from regions outside of Gujarat. Four artifacts from Harappa (including a Period 3B bead fragment) as well as a few from Mehrgarh, Nausharo and Chanhu-daro are geochemically more analogous to artifacts from Shahr-i-Sokhta, which could mean that they may have come from the same sources (presumably in the Helmand region) used by residents of that site. Or it might simply indicate that they are from an as of yet unsampled deposit that happens to be more geochemically analogous to Iranian sources than to Gujarati ones. Also, a few of the Gujarat provenience assignments for artifacts from Harappa and the other sites are, in my judgment, tenuous (especially certain ones from Mehrgarh). I believe it likely that those artifacts come from a source(s) to the west of the Indus Valley.

In the next chapter, I examine the acquisition of vesuvianite-grossular garnet – a translucent green-colored rock that has in the past been misidentified as "jade."

# CHAPTER 9

# VESUVIANITE-GROSSULAR ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: HARAPPAN "JADE"

In this chapter, I examine a distinctive translucent green to yellowish-green rock that has been recovered at Harappa in the form of beads, amulets and manufacturing debris (Figure 9.1). The Italian researchers Vidale and Bianchetti (1997) analyzed three of the debris fragments using X-ray diffraction (XRD) and determined them to be composed of a mixture of the minerals vesuvianite and grossular garnet (called here "vesuvianite-grossular"). They went on to suggest that translucent green beads from Mohenjo-daro (Figure 9.2 *top*), which were previously identified as "a peculiar form of jade" (Coulson 1931: 542), may actually be composed of this variety of stone. Reports of "jade" beads from early excavations at Harappa (Beck 1940: 402) and Mohenjo-daro (Mackay 1931c: 519, Mackay 1938: 498, 527), have led some scholars to suggest (Allchin and Allchin 1982: 186; Mackay 1948: 83) that long-distance exchange networks existed between the Indus region and distant parts of Asia where gem-quality nephrite (western China) or jadeite (Myanmar) can be found. Vidale and Bianchetti's identification of vesuvianite-grossular – a rock that greatly resembles jade and has several of the same mineralogical characteristics, casts doubt on those interpretation. More recently, the Italian team hypothesized (Vidale and Bianchetti 1999) that this stone may have even been a long-distance export from the Indus Civilization to consumers in Mesopotamia region.

I begin this chapter with an overview of the mineralogy of vesuvianite-grossular followed by an account of the effort to identify and characterize artifacts composed of it at Harappa. After that, the possibility that past researchers misidentified this rock as the mineral jadeite is explored. Next, I review the potential sources of this stone in South Asia and present the results of an INAA study in which samples from three of those sources were compared with artifacts from Harappa and Mohenjo-daro. I then consider Vidale and Bianchetti's hypothesis that vesuvianite-grossular may have been an export from the Indus region to Mesopotamia. In the concluding section, I explore the spatial and temporal distribution of vesuvianite-grossular at Harappa and discuss what appears to be its close association with "Ernestite," which is only material in the assemblage from which drills capable of perforating it could have been made. All sites, geologic sources and geographic regions mentioned in this chapter are identified on figures 9.7 and 9.8.

## THE MINERALOGY OF VESUVIANITE-GROSSULAR

The translucent green-colored stone that is the subject of this chapter is a rock composed primarily of two distinct minerals: vesuvianite and grossular garnet. In order to best understand the particular nature of this material and how it was used at Harappa, it is useful to be aware of each mineral's individual properties and variability.

Vesuvianite is a rock-forming silicate mineral first described in blocks of metamorphosed limestone on the slopes of Mt. Vesuvius (Pough 1988: 281). Its exact chemistry, structure and even official designation (which has alternated between vesuvianite and

*idocrase* several times in recent decades) are subject to continued debate (Allen 1985: 2). Several chemical formulae have been proposed over the years (Groat *et al*. 1992: Table 2). The most recent edition of *An Introduction to the Rock-Forming Minerals* (Deer *et al*. 1992) lists it as $Ca_{19}$ (Al, Fe)$_{10}$ (Mg, Fe)$_3$ $[Si_2O_7]_4$ $[SiO_4]_{10}$ (O,OH,F)$_{10}$. Published specific gravity (SG) values of pure vesuvianite range from 3.32 to 3.5 and its hardness is reported to fall between 6 and 7 on Mohs' scale (Deer *et al*. 1992: 47; Pough 1988: 280; Read 1979: 375). Vesuvianite is transparent to translucent and its color can range from yellow, green, to brown, with rare occurrences of red or blue (Deer *et al*. 1992: 47). The mineral most commonly occurs in areas resulting from the contact metamorphism of calc-silicate rocks (skarns), the metasomatic alteration of ultramafic rocks that results in rodingites (rodingitization – discussed on the next page) or, more rarely, in metasomatically altered alkali syenites (Allen 1985: 147-155). Pure vesuvianite is not a commonly used gemstone today, although it is known to occur both as "gemmy" pyramidal crystals and in a massive form that sometimes resembles jade (Pough 1988: 280-81).

Grossular is a member of the garnet group and has a chemical formula of $Ca_3Al_2Si_3O_{12}$ (Deer *et al*. 1992: 31). Like vesuvianite, it is a variable mineral. Published SG values range between 3.57 to 3.73 and its hardness may run from 6 up to 7.5 (Manson and Stockton 1982: Table 1). Pure grossular is colorless (ibid.: 207) but gem varieties have two distinct color trends: a yellow to orange to red-brown range called "hessonites" and a light yellow-green to dark green range called "tsavorites" (ibid.; Hansen 1986: xii). The mineral is transparent to translucent and occurs both as a crystal and in a massive form. Massive green grossulars from Africa and Pakistan are used jade simulants by jewellers in both countries (Qaiser *et al*. 1970: 735; Rothstein 1983: 611-13). Also like vesuvianite, grossular garnet forms in both regionally metamorphosed calc-silicate rocks and ultramafic rocks (most notably ophiolite sequences) that have undergone a metasomatic conversion sometimes called *rodingization* (Deer *et al*. 1992: 44; Hansen1986: xiii).

Although of different mineral families, the crystal structures of vesuvianite and grossular garnet are very similar (Groat *et al*. 1992: 22), with certain aspects being nearly identical in both (Deer *et al*. 1992: 47). The *c* axis of tetragonal vesuvianite is approximately equal to the length of the cubic edge of grossular (Allen 1985: 10). Thus, vesuvianite and grossular garnet, which form under similar conditions, frequently occur together. The term "californite" is informally used to describe a massive rock composed of vesuvianite and grossular garnet that may resemble jade (Rothstein 1983: 606) and which has a density of between 3.25 and 3.35 (Webster 1975: 232). It appears to be this co-occurring variety (which can grade in a single deposit from predominantly grossular to predominantly vesuvianite – Anderson 1966: 119) that is found at Harappa.

## CHARACTERIZATION AND IDENTIFICATION OF VESUVIANITE-GROSSULAR AT HARAPPA

There are several varieties of rocks and minerals such as serpentine, nephrite "jade," jadeite "jade," periodote and green quartz, for which vesuvianite-grossular may be mistaken. In fact, the three fragments from Harappa that Vidale and Bianchetti (1997) identified were originally classified as serpentine, as were most translucent green-colored varieties of stone encountered during HARP operations up to that point. For this reason, it was considered essential to reexamine all artifacts of this description recovered at the site. This was done in two stages. For the first, a set of 26 translucent green-colored debris fragments was assembled for an initial




**Figure 9.1** Vesuvianite-grossular garnet artifacts from Harappa.

round of mineralogical characterization involving XRD analysis and specific gravity (SG) testing. All samples were surface finds chosen to represent the full range of hues and material qualities (based on degree of internal fracturing) present in the sub-assemblage. XRD results and specific gravity determinations on these 26 have already been listed in Appendix 4.1. Seven of the samples underwent supplementary characterization using electron microprobe analysis (EMPA) – the details of which are provided in Appendix 9.1. For comparative purposes, five samples from two vesuvianite-grossular sources in Pakistan (described later in the chapter) were also analyzed (using XRD and EMPA) with the group. Informed by the results of these initial studies, the second stage of reexamination involved SG testing of all green-colored stone artifacts (translucent or otherwise) recovered at Harappa weighing 0.5 grams or more.

XRD analysis of the initial group of 26 archaeological samples revealed that, in every case but one (H94/4999-213, which turned out to be a flake of green-colored quartz), the fragments were composed

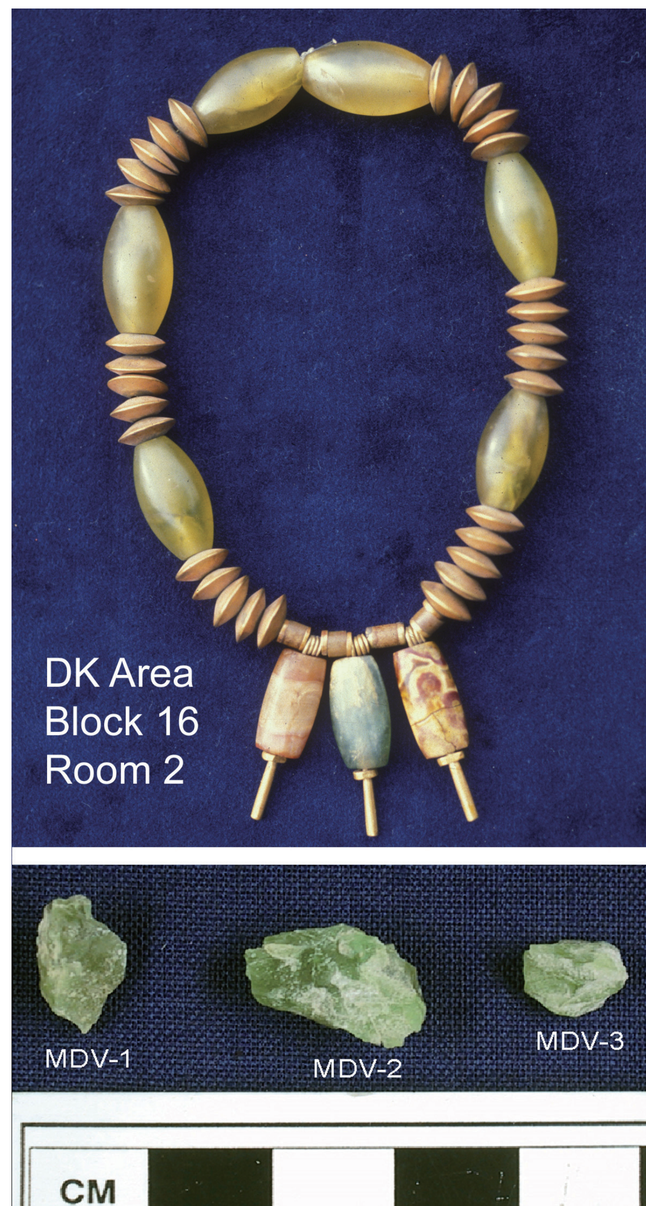



**Figure 9.2** Vesuvianite-grossular garnet artifacts from Mohenjo-Daro.

of either vesuvianite or grossular, or some mixture of both. Although it is not impossible that three distinct rocks and minerals (vesuvianite, grossular garnet and co-occurring vesuvianite-grossular) are represented among the samples, I consider it more likely that they all are fragments of the type of massive, heterogeneous vesuvianite-grossular rock sometimes called "californite." Chlorite (variety clinochlore) – a common constituent and/or weathering product of ferromagnesium rocks and minerals (Deer *et al.* 1992: 340), was also detected (either by XRD or EMPA) in approximately half of the samples analyzed and was the primary component in two of them.

To best conceptualize the range of compositional variability in the vesuvianite-grossular sub-assemblage at Harappa, recall Appendix 4.2 F – a composite of four of the XRD scans of debris fragments. The top scan (H2000/9999-91) shows a fragment that appears to be composed entirely of grossular garnet. However, EMPA scans of this sample showed that vesuvianite and chlorite, in amounts undetectable by XRD, was also present in the stone. Below this is a sample (H94/5106-8) that contains a secondary phase of vesuvianite, although still being primarily (as determined by peak intensity) composed of grossular. The third scan from the top (H90/3220-

4) shows a material that is primarily vesuvianite with a very minor phase of chlorite. The bottom scan (H94/5310-36) shows a fragment composed primarily of chlorite with a secondary phase of vesuvianite. Sample H94/5310-36, which is a highly fractured, cloudy pale-green flake, perhaps represents the unusable weathered exterior that was discarded during the processing of a vesuvianite-grossular blocklet. Most finished and unfinished vesuvianite-grossular ornaments recovered at Harappa are composed of clearer stone that contains substantially fewer fractures. The five geologic samples that were examined along with the initial group (Appendix 9.1) exhibit the same mineralogical variability and are more or less identical in appearance to vesuvianite-grossular artifacts from Harappa.

Specific gravity determinations were made on all 26 archaeological fragments (these are listed with the samples in Appendix 4.1) and the five geologic samples (listed with those samples in Appendix 9.1). Although the overall density range of vesuvianite-grossular appears extremely wide (from just under SG 3.0 to over 3.5), it must be remembered that it is a heterogeneous rock, rather than a pure mineral, that has been tested. When density values are considered together with the primary and secondary mineral phases of each sample an important trend is revealed (Figure 9.3). With the exception of the single fragment that turned out to be green quartz, the samples with the lowest SG are those in which chlorite is the primary component. The bulk of the samples are composed mainly of vesuvianite with occasional secondary components of grossular and/or chlorite. The samples having the highest SG values are those with grossular as their primary component. I show below that this trend from low density chlorite-dominated stone to high-density grossular-dominated stone is, to a certain degree, mirrored in the discard patterns of vesuvianite-grossular artifacts.

With an understanding of vesuvianite-grossular variability informed by the results of the initial XRD, EMPA and SG studies, all green-colored stone beads, pendants and ornament manufacturing debris fragments recovered at Harappa since 1986, as well as those from previous excavations on display in the Harappa Museum and its reserve collection, were re-examined during the 2003 field season. Many rock and mineral varieties, such as tourmaline, amazonite (microcline), malachite, turquoise, fluorite and green varieties of steatite, were easily distinguishable from vesuvianite-grossular based on their hardness, texture and/or crystal habit. Most green-colored artifacts composed of quartz (bloodstone, moss agate, green jasper) or opaque varieties of serpentine were likewise distinguished without difficulty. If there was any uncertainty at all, the low density of quartz (2.6) and serpentine (2.5 to 2.7) as compared to vesuvianite-grossular (≈ 3.0 to over 3.5) made definitive differentiation possible as the SG of most artifacts was tested. Density determinations could not be made on artifacts under 0.5 grams due to the inaccuracy of the SG balance below that weight. Thus, fragments of "micro-debitage" had to be identified based solely on their macroscopic properties. Ultimately, 543 artifacts from Harappa (including Vidale and Bianchetti's 3 samples and the 25 fragments characterized using XRD/EMPA) were classified (or re-classified) as vesuvianite-grossular.

Interestingly, when vesuvianite-grossular manufacturing debris, unfinished beads and finished ornaments are considered separately, their average densities are somewhat different (Figure 9.4). The mean SG of the 161 weighed fragments of vesuvianite-grossular ornament manufacturing debris is 3.28. The mean of the 11 unfinished beads is 3.35 and the mean of the 10 finished ornaments is 3.31. Although the density discrepancies might be due to small numbers of finished and unfinished items considered, it may also be indicative of a pattern relating to the use and discard of this type of stone. The lower average density overall for manufacturing debris could reflect the intentional discard of more fractured

and weathered stone. Such material tends to have a higher content of chlorite (a mineral with an average density of around 2.65) and so would naturally have a lower SG than less fractured/weathered forms of vesuvianite-grossular. Conversely, the high mean density for unfinished vesuvianite-grossular beads may indicate that the stone becomes more difficult to work as its grossular content increases. Recall that grossular can have a hardness of up to Mohs 7.5 while the hardest drills used by Harappans (made of microcrystalline silicate or "Ernestite") were only around 7. Thus, partially perforated bead blanks (such as the one pictured in Figure 9.5) were likely discarded because their high grossular contents (indicated here by their high densities) rendered them undrillable.

## IS VESUVIANITE-GROSSULAR HARAPPAN "JADE"?

In an appendix to his report on beads excavated at Harappa, Beck listed (1940) five examples composed of "jadeite." Beads said to be made of the same mineral were also reported among jewelry hoards discovered in the later levels of Mohenjo-daro's DK (Mackay 1931c: 519, Marshall 1931b: Plate CXLVIII a) and HR areas (Marshall 1931b: Plate CL; Sahni 1931a: 194). That these artifacts were genuine "jade" (either the mineral jadeite or the rock nephrite) has long been taken for granted by scholars (Chakrabarti 1990: 142; Lahiri 1992: 78-79; Mackay 1938: 498; Piggott 1950: 174; Ratnagar 2004: 149; Wheeler 1968: 80) who point to the supposed presence of that stone as evidence for Harappan long-distance trade with peoples in source areas external to the Greater Indus region – namely in Central and/or East Asia. Vidale and Bianchetti have suggested (1997) that the "jade" beads reported from early excavations at Harappa and Mohenjo-daro may actually be composed of vesuvianite-grossular. In this section, I evaluate that possibility.

Some of the supposed "jade" beads from those early excavations are pictured at the beginning of this chapter. HM5339 in Figure 9.1 is from the Harappa Museum collection. Horace Beck did not provide details in his report as to how he came to the conclusion that beads like this one were composed of "true jadeite" (1940: 402). He did, however, note that they seemed to be "unusually transparent" for jade (ibid.). A portion of a necklace with "jade" beads from the DK Area hoard at Mohenjo-daro is pictured in Figure 9.2, *top image*. A.L. Coulson of the Geological Survey of India employed a variety of basic mineralogical tests in the analysis of these artifacts and others like them (Coulson 1931: 538-42). The density of the 23 examples he studied ranged from 3.225 to 3.395, with an average of 3.34. The hardness of two of those beads was judged to be 7.5 and the refractive index (RI) of one determined to be 1.651 ± .002. Like Beck, Coulson noted that the green to yellowish-green material seemed to be "more translucent than most varieties of jade" (ibid.: 542) and twice referred to it (ibid.: 539, 542) as a "peculiar" form of that stone. The finished condition of the ornaments obscured the stone's fracture and texture – characteristics that could have provided additional clues as to its identity.

Given the limited information that Coulson and Beck were able to glean from the beads they examined, the conclusion that they were made from jadeite is understandable. The shade of green the stone exhibits is reminiscent of that mineral and, although somewhat rare, highly translucent varieties (such as *Imperial Green Jadeite*) are known to occur (Levy and Scott-Clark 2001). Moreover, the measured SG and RI values of the Mohenjo-daro beads were consistent both with published values for jadeite and those of the jade specimens that Coulson examined in the Geological Survey of India's collections (particularly those from Burma). There are, nonetheless, several reasons to believe that the beads in question were misidentified and are actually

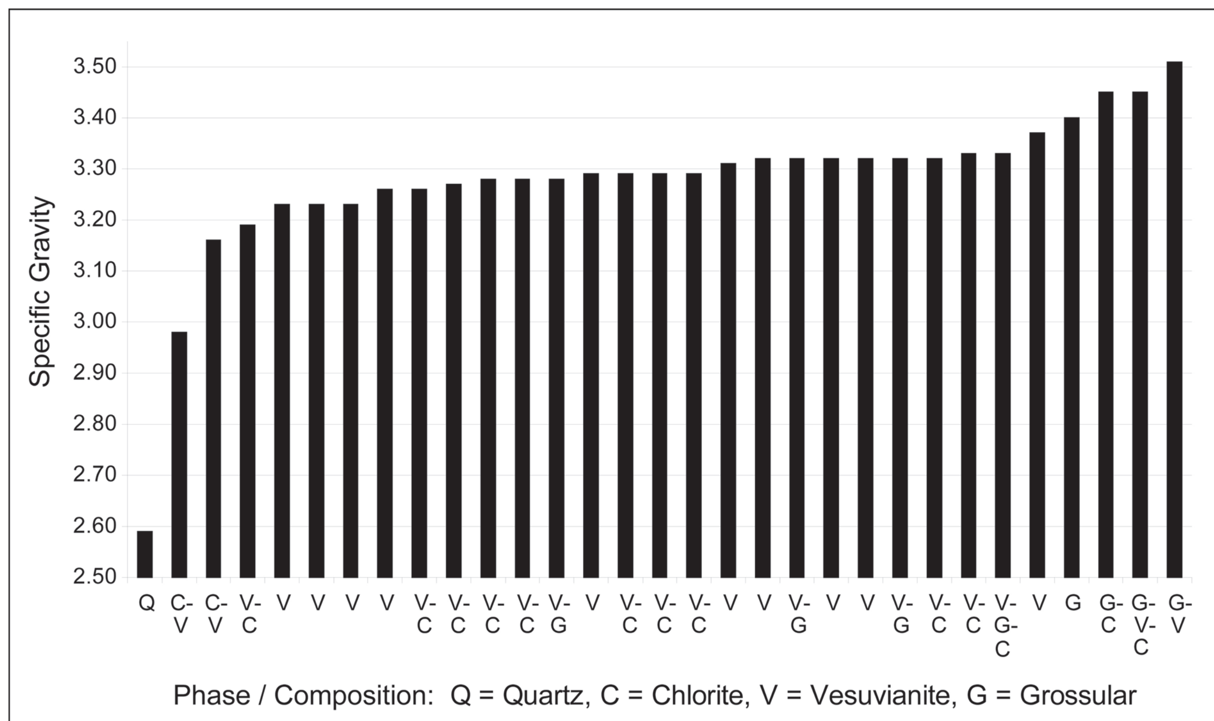



**Figure 9.3** Specific gravity and composition of 31 translucent green-stones (26 debris fragments from Harappa and five geologic samples).

composed of vesuvianite-grossular.

To begin with, the co-occurring variety of vesuvianite and grossular garnet has a very "jade-like character and may pass for the genuine material, especially" since it and jadeite have *overlapping* specific gravity values (Webster 1975: 232). So, although it is the case the densities of the beads Coulson tested from Mohenjo-daro all fell within (or very near) the density range of jadeite (SG 3.24 to 3.43 – Deer *et al*. 1992: 192), they were also equally consistent with the density range of vesuvianite-grossular. Another important point to observe is that Coulson's estimated hardness of the "jade" beads was Mohs 7.5. That value is much more characteristic of a stone containing grossular than it is of jadeite, which has a *maximum* hardness of Mohs 7 (Schumann 1977: 154) and is usually more around Mohs 6 (Deer *et al*. 1992: 192). Finally, vesuvianite-grossular is sold as "jade" in the bazaars Pakistan today. I have analyzed samples purchased in both Peshawar (Figure 9.6) and Quetta that are mineralogically analogous to artifacts composed of that stone at Harappa. Perhaps most significantly, the visual appearance of this material is *identical* to the "jade" beads in question. Given this and the other physical characteristics that those beads exhibit, I find it far more probable that they were made from vesuvianite-grossular rather some "peculiar" form of jadeite.

Of course, nothing presented above definitively proves that the so-called "jadeite" beads from early excavations at Indus Civilization cities are actually made from vesuvianite-grossular. In order to do that it would be necessary to directly test them. However, I can state that I know of no other variety of rock or mineral (including genuine jadeite) that accounts for the appearance and reported properties of those beads more satisfactorily than vesuvianite-grossular. I can also report that this stone has now been positively identified at Mohenjo-daro (Appendix 9.2). Six small translucent green stone fragments (three of which are pictured in Figure 9.2, *bottom image*) were provided to me by Dr. Massimo Vidale, who collected them from the site's "Moneer" Area (Vidale 1987a, 1990) during the IsMEO-Aachen University project (Jansen

**Figure 9.4** Specific gravity range and mean of different types of vesuvianite-grossular artifacts from Harappa

| Artifact type | *amount* | *SG range* | *mean SG* |
|---|---|---|---|
| **Unweighed "micro-debitage"** | 361 | n/a | n/a |
| **Weighed debris fragments** | 161 | 2.98 to 3.52 | 3.28 |
| **Unfinished beads** | 10 | 3.30 to 3.50 | 3.35 |
| **Finished ornaments** | 11 | 3.32 to 3.45 | 3.31 |

and Urban 1984). These samples are mineralogically analogous to vesuvianite-grossular debris fragments found at Harappa.

## WHERE DID THE VESUVIANITE-GROSSULAR ACQUIRED BY HARAPPANS COME FROM?

In this section, I attempt to shed light on the question of where Indus Civilization craftspeople obtained the massive variety of vesuvianite-grossular that they used to make beads and amulets. I first examine potential sources of that stone in India and Pakistan. While doing this brief mention is also made of certain geologic occurrences that I do *not* consider to be potential sources, either because they are too distant (those in far eastern India for example) or because the nature of the stone found at those locations is not the same as the material used by Harappans. After reviewing both potential and unlikely sources, I present the results of an INAA study in which vesuvianite-grossular samples collected from three occurrences in three different regions – Rajasthan, Balochistan and the FATA, were compared to fragments of that stone recovered from Harappa and Mohenjo-daro. All archaeological sites, geologic occurrences and geographic regions discussed in this section are identified on figures 9.7 and 9.8.

### Potential vesuvianite-grossular sources in India

Scholars studying vesuvianite-grossular artifacts found at sites in both South Asia (Vidale and Bianchetti 1997: 951-52) and West Asia (Sax 1991: 113) have pointed to the Indian state of Rajasthan as a possible source of that stone. Although the region is indeed rich in many varieties of garnet (Geological Survey of India 2001b: 64-65), grossular garnet (green or otherwise) has not yet been reported in the geologic literature as occurring there. Vesuvianite, on the other hand, is known (although not particularly well) from several places in Rajasthan. Middlemiss (1921: 20) made an oblique reference to a sample of vesuvianite in the Tonk Museum, which was said to be from a quarry near Rer in the eastern part of the state. However, no other information was provided on either the sample (its color, to crystal habit, etc.) or its source. Vesuvianite is mentioned as a mineral associated with skarn rocks round Kararavav in the Pali District of southwestern Rajasthan (Rathore 1991). Although no further details were given regarding that occurrence, it is likely related to another one nearby within Kumbhalgarh Forest Reserve in the adjacent Rajsamand district, which I first learned about in 2003.

In March of that year, while visiting with a jeweler in Udaipur, Rajasthan, I was shown a string of semi-translucent green beads (Figure 9.9) along with the raw stone from which they were made. The green hue of the beads was somewhat deeper than the typical vesuvianite-grossular artifact from Harappa



**Figure 9.5** Unfinished vesuvianite-grossular bead H96/7106-6 (SG = 3.50).

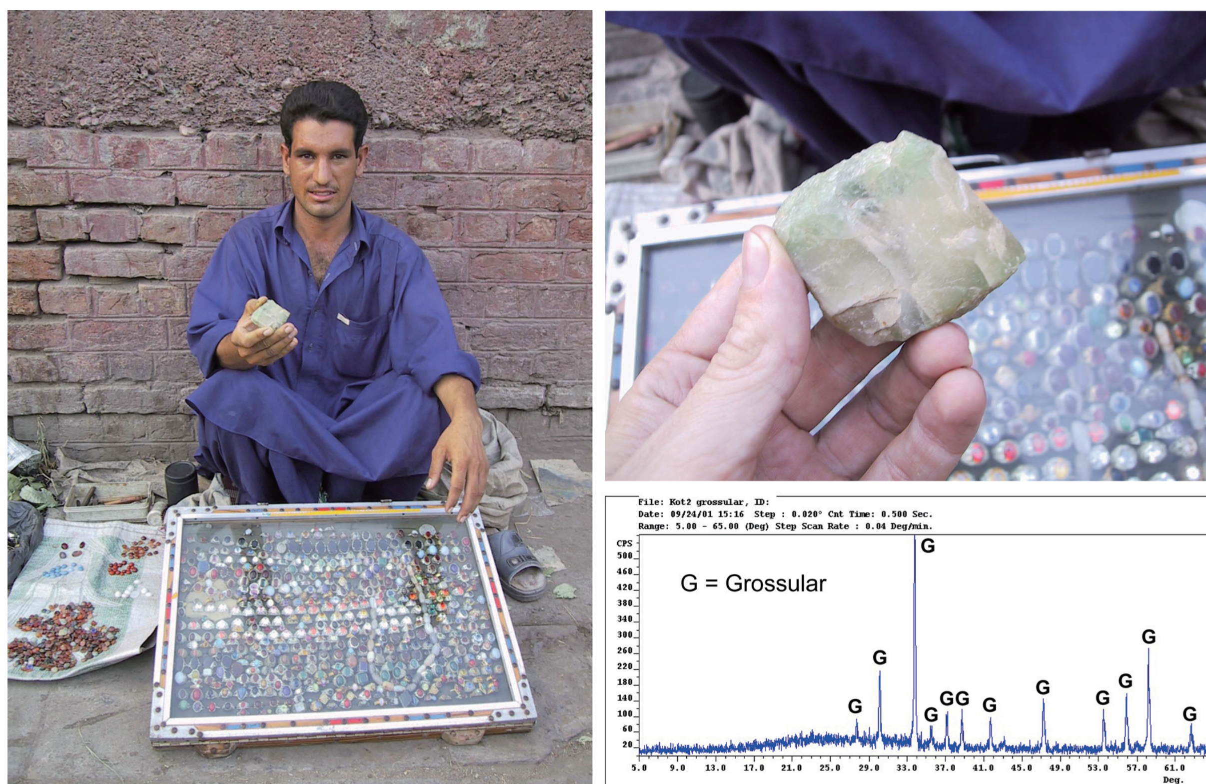



**Figure 9.6** Johri in Peshawar, Pakistan selling raw "jade" (said to be from Sakhakot-Qila) that was later identified at grossular garnet.

but the stone, although highly fractured, was massive, compact and seemed to be fairly dense, which was much more like vesuvianite-grossular than other locally available green stones such as serpentine or aventurine quartz. I arranged to meet the man from whom the jeweler purchased the stone. That man was unwilling to either take me to the stone's source or give me much information about its location except to say that it was "in the forest." I was, however, able to acquire many samples (Figure 9.10). A few weeks later I related this story to N.K. Sood, Director–Geological Survey of India at Jaipur. Although he

**Figure 9.7**: Vesuvianite-grossular sources of the Greater Indus region and archaeological sites discussed in this chapter.

Shortughaï
Sakhakot-Qila
BAJAUR
SWAT
Ghalegay
MALAKAND
Peshawar Valley
KHYBER
HAZARA
Hathial
Sarai Khola
KOHAT
N W F P
H I M A L A Y A S
A F G H A N I S T A N
Jhelum River
Chenab River
Ravi River
Beas River
Sutlej River
Ghaggar River
Hakra River
P U N J A B
Harappa
ZHOB
Muslimbagh Ophiolite
Taleri Mohammed Jan
Dabar Kot
Bolan River
Indus River
B A L O C H I S T A N
KHUZDAR
Mohenjo-daro
Las Bela Ophiolite
S I N D H
R A J A S T H A N
A R A V A L L I S
Rer
Kararavav
Kumbhalgarh
Udaipur
A R A B I A N S E A
Dholavira
Dharol Hill
G U J A R A T
Lothal
N
0 km 200 400

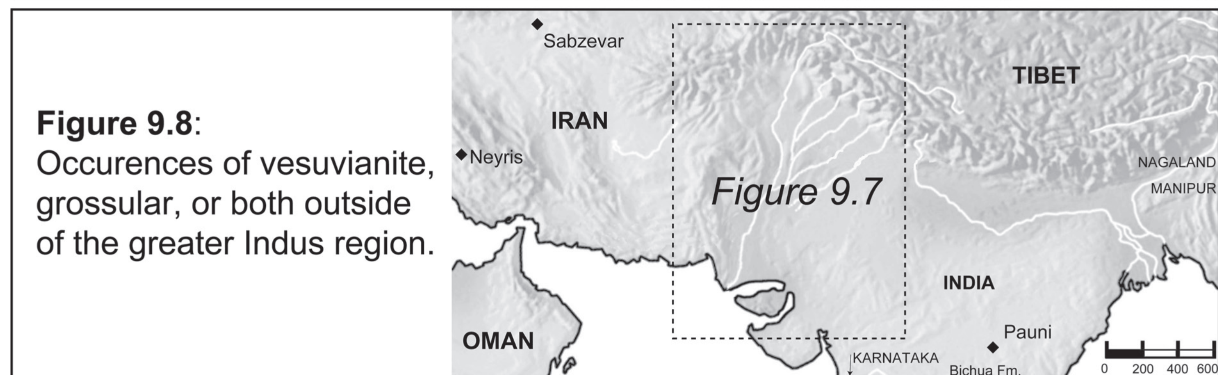



**Figure 9.8**: Occurences of vesuvianite, grossular, or both outside of the greater Indus region.




**Figure 9.9** A string of Kumbalgarh vesuvianite beads purchased in Udaipur, Rajasthan.



**Figure 9.10** Masses of Kumbalgarh vesuvianite purchased from a stone merchant near Udaipur.

was not certain at the time of the stone's composition, he was able to confirm that it could be found in Kumbhalgarh Forest Reserve, Rajsamand District of southern Rajasthan. He said that Bhil tribesmen in the area were mining the stone and showed me a sample of that material that they had provided to him. It appeared to be identical in every way to the samples that I had acquired from the stone merchant living near Udaipur.

I analyzed the Kumbhalgarh stone using XRD upon my return to Madison and found it to be pure vesuvianite (Appendix 9.3). Although there was no indication of grossular or chlorite in the XRD peak profile of the single sample that I studied, the same is actually true of many of the debris fragments analyzed from Harappa. As I noted above, the appearance

of the Kumbhalgarh stone is slightly different than typical Harappan vesuvianite-grossular. Still, among the flakes at Harappa there are a few deeper green and highly fractured examples. That such material was sometimes used to make ornaments is evident from the truncated conical amulet numbered H90-3037-36, which is pictured in Figure 9.1. Therefore, Kumbhalgarh Forest could be a potential source of this stone.

Elsewhere in India, green garnet occurs at several locations in Karnataka (Parthasarathy *et al*. 1999; Viswanathiah *et al* 1979; Somasekar and Naganna 1966) but it is of the uvarovite garnet variety. Grossular garnet and vesuvianite are found together (but only as small grains) in the calc-schists of the Bichua formation of central India (West and Sharma 1989: 497). A showing of vesuvianite was reported from a chromite mine in the Pauni ultramafics of Maharashtra but no information was given as to its color (Mahajan and Singh 1984: 11). Vesuvianite and vesuvianite-grossular occur in veins a few inches across at Dharol Hill in northeast Gujarat (Middlemiss 1921: 20-21). The material at this location is described as translucent to transparent brown, however.

Translucent green vesuvianite-grossular can be found near the border Myanmar border in the far eastern part of India. Rodingitized volcanic dykes in ophiolitic rock in the states of Manipur (Shukla 1989) and Nagaland (Ghose *et al*. 1986) are reported to contain large masses of this material. Although it is not impossible that massive vesuvianite-grossular from these distant sources found its way to Harappa (over 2200 km away), there were much closer sources in regions that today are within modern Pakistan.

### Potential vesuvianite-grossular sources in Pakistan

There are three regions in Pakistan where vesuvianite or vesuvianite-grossular has been positively identified: the FATA, northern Balochistan and southern Balochistan

Massive varieties of translucent green vesuvianite-grossular occur at several places in the bordering Malakand, Mohmand and Bajaur Agencies of the FATA (Kazmi 1995b: 286; Kazmi and Jan 1997: 477). Volcanic dykes running through the Sakhakot-Qila ophiolite, which is located on the northwestern fringe of the Peshawar Valley along the Malakand-Mohmand border, contain extensive lenses of massive vesuvianite-grossular with occasional chlorite impurities and inclusions of chromite and magnetite (Qaiser *et al*. 1970, 1972; Ahmed 1987a, 1988a, 1988b). Qaiser and others (1970: 735) noted that stone from this area "has been sold locally as 'jade'." Samples from this source (Figure 9.11) were obtained in the Peshawar bazaar and provided by the late Dr. Syed Hamidullah of the Center of Excellence in Geology, University of Peshawar.

Near the village of Taleri Mohammed Jan in the Zhob District of northern Balochistan, the metasomatic alteration of a dolerite dyke in the Muslimbagh ophiolite resulted in the formation of vesuvianite, grossular and clinochlore (Bilgrami and Howie 1960, Bilgrami 1960, Bilgrami 1963: 1176-77). In May of 2001, I visited this occurrence (Figure 9.12) with Dr. Khalid Mahmood of the Center of Excellence in Mineralogy, University of Balochistan, Quetta. We collected samples from an area of rodingite bearing a vein of translucent, but highly fractured green vesuvianite-grossular. Although no evidence of ancient mining was observed here, the massive talus-like debris field surrounding the source suggested an extended and/or intensive period of exploitation. Local residents reported that during the British Era much larger masses of material could be found at this location. Kazmi noted (1995b: 286) that vesuvianite had recently reappeared in the bazaars Quetta indicating the possibility that local tribesmen had discovered a new source. I obtained several additional samples of massive vesuvianite-grossular in Liaqat Bazaar, Quetta during the spring of 2001, which were said to be from a new source in




**Figure 9.11** Samples of vesuvianite-grossular from the Sakhakot-Qila ophiolite, Malakand-Mohmand agencies, FATA.

the Muslimbagh ophiolite.

Translucent green crystals occurring in the northern part of the Las Bela ophiolite in the Khuzdar District, southern Balochistan were identified using XRD as vesuvianite by Armbruster and Gnos (2000: 112). The crystals were, however, all less than 1 mm in size. Although no massive bodies of vesuvianite-grossular have yet been reported in this area, the geology of the region (rodingization of calcium-rich rock) is such that they could exist.

### An INAA comparison of vesuvianite-grossular artifacts to samples from three sources

Ten vesuvianite-grossular artifacts – seven debris fragments from Harappa and three from Mohenjo-daro – were compared to samples from three potential geologic sources (Sakhakot-Qila, Taleri Mohammed Jan and Kumbhalgarh Forest) in South Asia using INAA-derived elemental data, canonical discriminant analysis (CDA) and cluster analysis (CA). Details relating to sample preparation, INAA and data evaluation using CDA and CA have already been discussed in Chapter 3. The INAA results for the artifacts are listed in Appendix 9.4 and those for the geologic sources can be found in appendices 9.5 and 9.6.

Although the seven vesuvianite-grossular artifacts from Harappa in the comparative set (pictured in the bottom image of Figure 9.1) represent a mere 1.3% of the sub-assemblage of that rock variety, they were carefully selected to be as spatially and temporally representative as possible (see columns two through four of Appendix 9.4 for information on their Period, Mound and Trench associations). All are from stratigraphically secure contexts (together they represent around 4% of the 180 vesuvianite-grossular artifacts from such contexts). There is at least one example in the set from each chronological phase in which this variety of stone has been recovered (periods 1, 3B, 3C and 5). As only one vesuvianite-grossular flake each was found in periods 1 and 5 levels, and only four flakes are associated with Period 3B levels, the analysis of these artifacts represent a 100%, 100% and 25% (respectively) sample of those chronological sub-assemblages. Each of the four major mounded areas at the site is represented in the set by at least one artifact.

The three vesuvianite-grossular artifacts from Mohenjo-daro (pictured in Figure 9.1, *bottom image*) were provided by Dr. Massimo Vidale. All are surface finds that he collected during his research on lapidary craft industries at the site's "Moneer" Area (Vidale 1987a, 1990). The three artifacts (MDV-1, MDV-2 and MDV-3) are from among the six flakes I previously analyzed using XRD (Appendix 9.2).



**Figure 9.12** Top - The rodingite outcrop and talus slope of the vesuvianite-grossular occurrence at Taleri Mohammed Jan, Zhob District, Baluchistan. Bottom - Veins of fractured vesuvianite-grossular at Taleri Mohammed Jan.

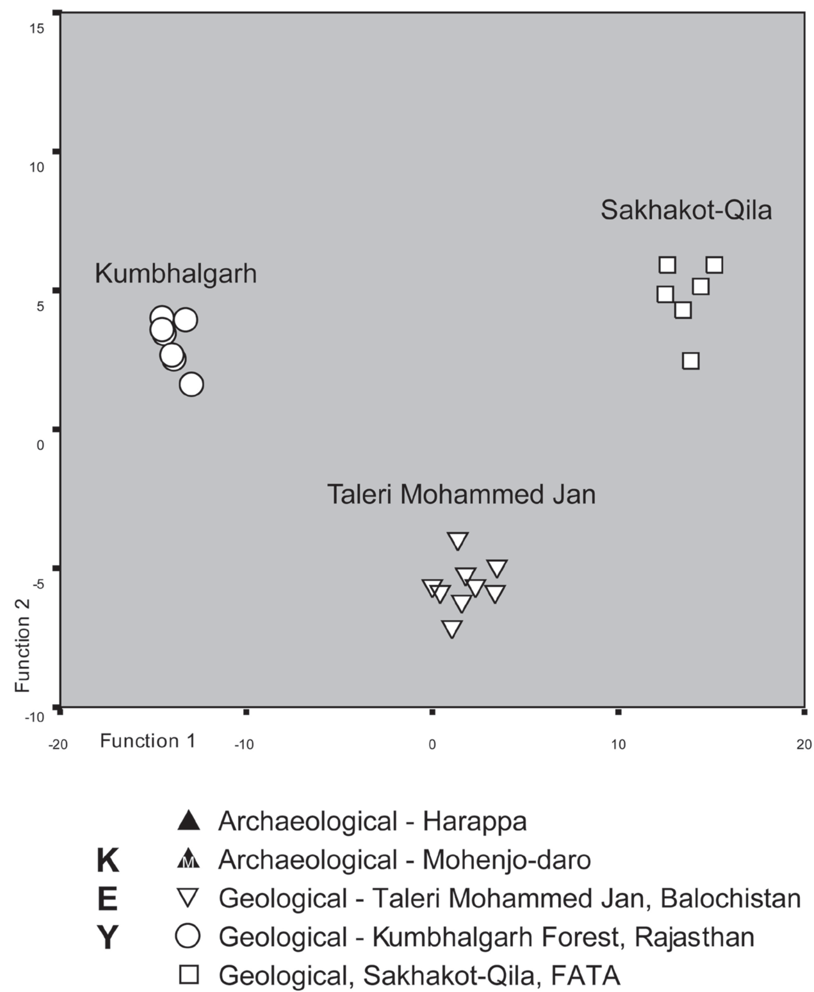
Twenty-two samples from three vesuvianite-grossular sources comprise the set of geologic comparative material. Six are from rodingite veins in the Sakhakot-Qila ophiolite, Malakand/Mohmand agencies, FATA. Nine are from Taleri Mohammed Jan, Zhob District, Balochistan. Seven are from the reported vesuvianite occurrence in Kumbhalgarh Forest, Rajsamand District, Rajasthan.

INAA of the comparative set yielded 13 elements (Al, Ce, Co, Cr, Eu, Fe, Mn, Na, Sc, Sm, Sr, U and V) suitable for multivariate statistical analysis. These data were first examined using CDA. (Appendix 9.7 lists the standardized [canonical] discriminant function coefficients for that figure). Outstanding separation between the three geologic sources was achieved (Figure 9.13 *top*). Application of the leave-one-out classification function resulted in a 100% grouped sample cross-validation success rate, which indicates that the three sources are also highly distinct statistically. When the artifacts were plotted as ungrouped cases in relation to the geologic samples (Figure 9.13 *bottom*), the predicted group membership for eight of ten was the Sakhakot-Qila source. Two artifacts – one from Period 3C at Harappa (H94/4898-83) and one from Mohenjo-daro (MDV-3) were predicted to belong to the Taleri Mohammad Jan source (both artifacts are labeled on the bottom plot of Figure 9.13).

The vesuvianite-grossular artifact and source sample data were also examined using hierarchical cluster analysis. Multiple clustering strategies were employed. Figure 9.14 is a dendrogram generated using Ward's method. Six alternate strategies can be seen in Appendix 9.8. All produced dendrograms that were remarkably similar. With regard to the geologic sources, the Kumbhalgarh Forest samples (Raj-K) always formed a cluster that was completely distinct from the other two geologic sources examined. Those two – Sakhakot-Qila (FATA-SQ) and Taleri Mohammad Jan (BZ-TMJ), together formed a second larger cluster indicating that, geochemically, they were much more similar to one another. This is not altogether surprising as they are both associated with the ophiolite formations that are found intermittently along the northern and western margin of the Indus Basin. Within that second large cluster, however, the Sakhakot-Qila and Taleri Mohammad Jan sources either overlap minimally or, depending on the clustering strategy used, not at all.

Turning to the artifacts, once again, none even remotely resemble the Kumbhalgarh source. An examination of the dendrograms indicates that the same four artifacts consistently group closely with the either the Sakhakot-Qila or Taleri Mohammad Jan sources. Sample H94/4898-83 groups closely with the Taleri Mohammad Jan samples while H98/8908-8, H99/9730-11 and MDV-3 groups with those from Sakhakot-Qila. (note that CDA had previously assigned MDV-3 to the Taleri Mohammad Jan source). The six remaining artifacts consistently grouped together to form a cluster that, although clearly more closely related to those two sources than to the Kumbhalgarh source, is still very distinct in itself. This suggests that these artifacts may be from a fourth vesuvianite-grossular source that is not represented among the geologic sample set. As previously indicated by CDA, the artifacts forming that cluster are statistically more closely related to the Sakhakot-Qila source than they are to the Taleri Mohammad Jan source. It is probable, therefore, the unknown source is one of the several as yet of un-sampled vesuvianite-grossular deposits reported to exist in the Mohmand or Bajaur agencies of the FATA.

In conclusion to this section, the ten vesuvianite-grossular artifacts from Harappa and Mohenjo-daro analyzed for this study almost certainly came from an occurrence located along the northwestern margin of the Greater Indus region rather than from Rajasthan. Most seem to have been derived from an FATA source but a few may have come from one in northern Balochistan. Although no Indus Civilization settlements can be found in the immediate vicinity of either source, both lie along what may have been major trade and communication routes during the third millennium BC. Harappans might have passed through or near the Malakand or Mohmand areas of the FATA on their way to and from the outpost of Shortughaï in northern Afghanistan. Taleri Mohammad Jan lies at the southern end of the



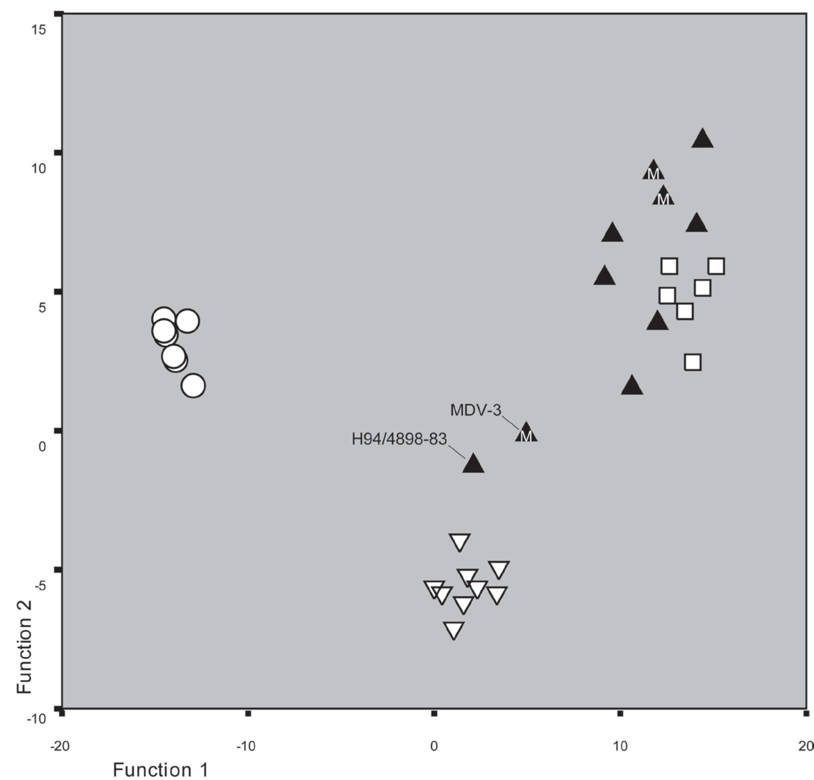




**Figure 9.13** Comparison of samples from three vesuvianite-grossular sources and ten vesuvianite-grossular artifacts using canonical discriminant analysis.

Zhob Valley (an important route through northern Balochistan today) and is around 130 km northwest of the Indus Civilization settlement of Dabar Kot.

## WAS VESUVIANITE-GROSSULAR EXPORTED TO MESOPOTAMIA FROM THE GREATER INDUS REGION?

In reference to reports of artifacts made of vesuvianite-grossular at third millennium BC sites in Mesopotamia, Vidale and Bianchetti (1999) hypothesized that this variety of stone may have been exported to that region from South Asia. Earlier, Margaret Sax (1991) had made a similar suggestion with regard to first millennium B.C Mesopotamian cylinder seals composed of the same material. In this section, I first briefly discuss the possibility that Harappans exported vesuvianite-grossular west of the Greater Indus region. I then review potential sources of that stone that, as compared to those in South Asia, may have been more accessible to consumers in western Asia.

There is no reason why vesuvianite-grossular (or any other material for that matter) could not have been traded from South Asia to the Mesopotamia region during the third millennium B.C or later. As previously noted, green stone fragments and beads visually identical to the vesuvianite-grossular artifacts positively identified at Harappa and Mohenjo-daro are present in collections from the Indus Civilization city of Dholavira in northern Gujarat (*personal observation*). From there and other southern coastal settlements, this stone could have easily been transported to consumers in West Asia via maritime trade routes, which were clearly active at this time (Possehl 1997a). Overland exchange could have taken place via any number of pathways (many of which are outlined in Chakrabarti 1990 and in Ratnagar 2004). Vesuvianite-grossular might very well have been moved along the same routes through which "inter-cultural" style chlorite vessels were traded from highland Iran to inland settlements across a broad area extending from the Indus Valley to West Asia (Kohl 1975; Lamberg-Karlovsky 1993). Indus Civilization peoples clearly had the capability and connections necessary to export this valuable stone to consumers the west. The pertinent question now is whether or not Mesopotamian consumers had access to alternate sources of vesuvianite-grossular.

A review of the geologic literature reveals numerous potential vesuvianite-grossular sources that, as compared to those of northwestern South Asia, would have been closer to consumers in Mesopotamia. A massive occurrence of this stone is reported (Alberti *et al*. 1976) in rodingitized rock in the Sabzevar ophiolite, Khorassan Province, northeastern Iran (see Figure 9.8). Nearer to the Mesopotamian heartland (not pictured on Figure 9.8) is a vesuvianite-grossular source in the Neyriz Ophiolite Complex of the southern Zagros Range, Iran (Adib and Pamic 1979). Stone from that locality might have been acquired through Mesopotamian interaction with the ancient groups inhabiting those resource-rich highlands (Henrickson 1994). The grossular described (Ahmed 2002) in the al-Madhiq region of southwest Arabia is brownish-red in appearance but it is possible that there are sources of green-colored stone elsewhere in western Asia that remain to be identified. Ophiolites containing the skarn rock / rodingite formations in which massive vesuvianite-grossular tends to form are found a various other points along northern Zagros Range and into the highlands of Anatolia (Cogulu 1980; Schandl and Mittwede 2001). A source of the massive green variety could eventually be found in those regions.

Although Harappans could have exported vesuvianite-grossular to Mesopotamia, consumers in that region probably had access to closer sources of the stone. To test Vidale and Bianchetti's hypothesis (1999), it will be necessary to compare Mesopotamian

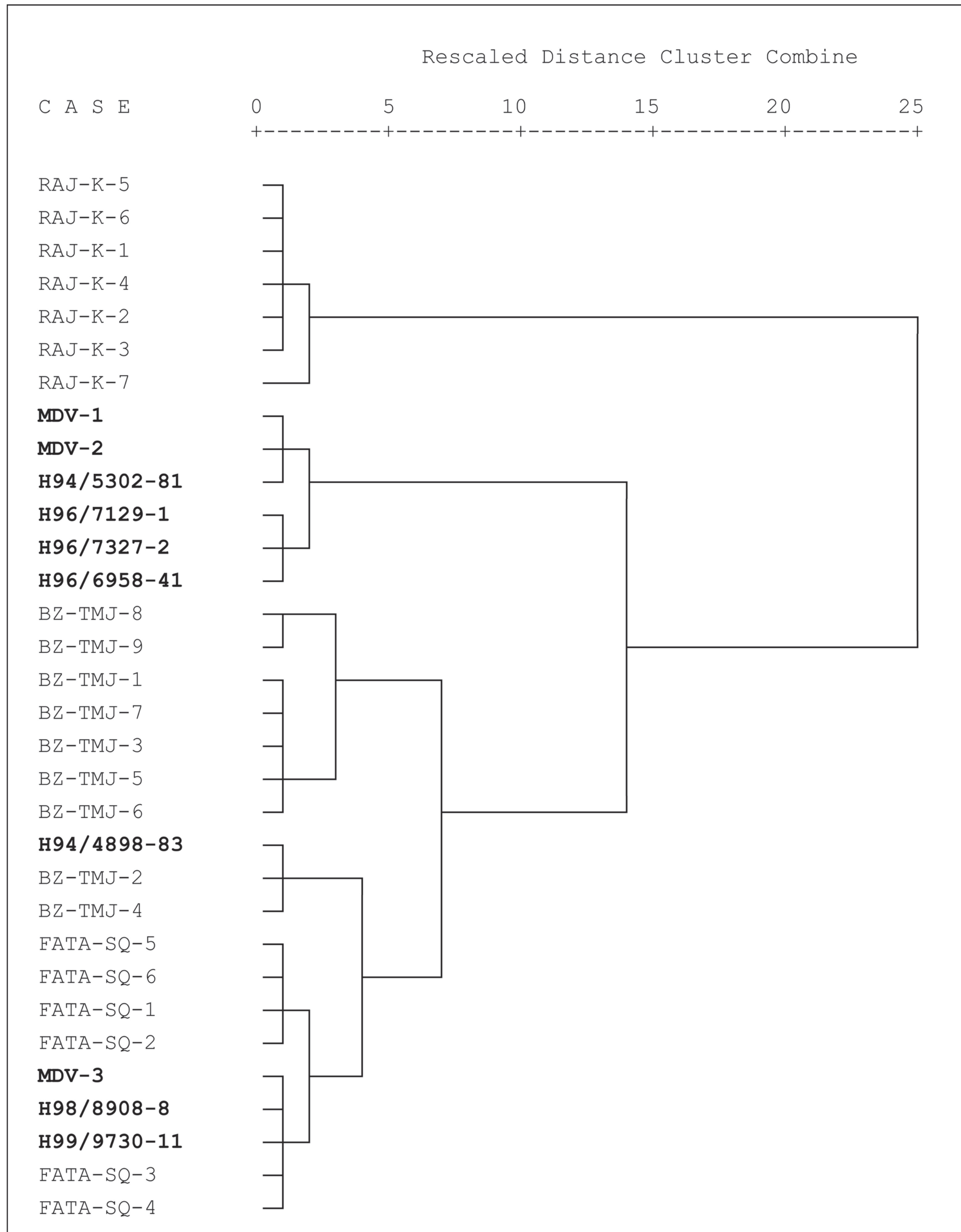



**Figure 9.14** Comparison of samples from three vesuvianite-grossular sources and ten vesuvianite-grossular artifacts using hierarchical cluster analysis (Ward's Method).

artifacts with sources analyzed in this chapter and samples collected from West Asian occurrences.

## VESUVIANITE-GROSSULAR AT HARAPPA AND ITS ASSOCIATION WITH "ERNESTITE"

In this final section, I examine the spatial and temporal distribution of vesuvianite-grossular artifacts at Harappa and discuss what I believe is an interesting and important association between that material and another variety of rock found at the site – "Ernestite."

The 543 artifacts classified as vesuvianite-grossular at Harappa comprise 0.96 % of the site's entire stone and metal assemblage – just short of the (admittedly arbitrary) 1% value above which I defined materials as major rock or mineral varieties. The only stones used more by bead-makers were steatite and microcrystalline silicates. Vesuvianite-grossular is three times as abundant at Harappa as lapis lazuli, which is a material that has received considerably more attention from scholars (see Appendix 4.4). A similar pattern may exist at Mohenjo-daro. Few lapis lazuli artifacts have been reported at that site but it now appears as if numerous items, such as the beads previously identified as "jade" and rock fragments once thought to be serpentine (Vidale 2000: 42), are composed of vesuvianite-grossular. Whether or not that stone was as widely distributed across the Indus Civilization as lapis lazuli remains to be determined but, as I have already noted, it seems to be present as far south as Dholavira. Although it may eventually be discovered that vesuvianite-grossular artifacts were relatively abundant and widespread, the evidence from Harappa indicates that the stone's use, at least at that site, was rather restricted in space and time.

The numbered trenches and labeled areas on Figure 9.15 indicate those parts of Harappa from which vesuvianite-grossular artifacts have been recovered. The inset pie-chart on that figure shows how this material sub-assemblage was differentially distributed among site's major areas. The first four columns of Figure 9.16 provide a more detailed picture of the sub-assemblage's composition and its distribution among those excavation trenches and survey areas from which it was recovered. Slightly more than 91% of all vesuvianite-grossular artifacts at Harappa came from mounds E and ET (the heaviest concentration is in the area straddling the east-southeast side of mound E and the west-southwest side of mound ET). Fifty-three vesuvianite-grossular artifacts were recovered elsewhere at the site. The majority of those (n = 41) came from off-mound Harappa Period dumps above the cemetery area and the Low Western Mound. A mere five were found on mound AB and only four on Mound F. One flake was found in the area of the Mughal Sarai (just to the south of Mound E). Lastly, there are two beads from the Harappa Museum collection included in the vesuvianite-grossular sub-assemblage. Although their precise context is unknown (they did not possess any identifying numbers), it is not unlikely that they are from among the five "jadeite" beads listed in Beck's report (1940: 413-414), four of which reportedly came from Mound F and one from Mound D (≈ Area J near the Low Western Mound and south of Mound AB).

Three hundred sixty-three (or approximately two-thirds) of the 543 vesuvianite-grossular artifacts at Harappa are from surface or disturbed deposits. Of the remaining 180 artifacts recovered from stratigraphically secure deposits (see Figure 9.17 *third row*), all but six come from Period 3C levels. Four were recovered in Period 3B levels. A single flake was found in Ravi Phase (Period 1) levels (Trench 39, Mound AB). Although the flake appears to be from a secure excavation lot, there is a possibility that it is a later phase artifact that was re-deposited by rodent action, which is common in those levels (although great care is taken to identify such disturbances). Another individual flake of vesuvianite-grossular

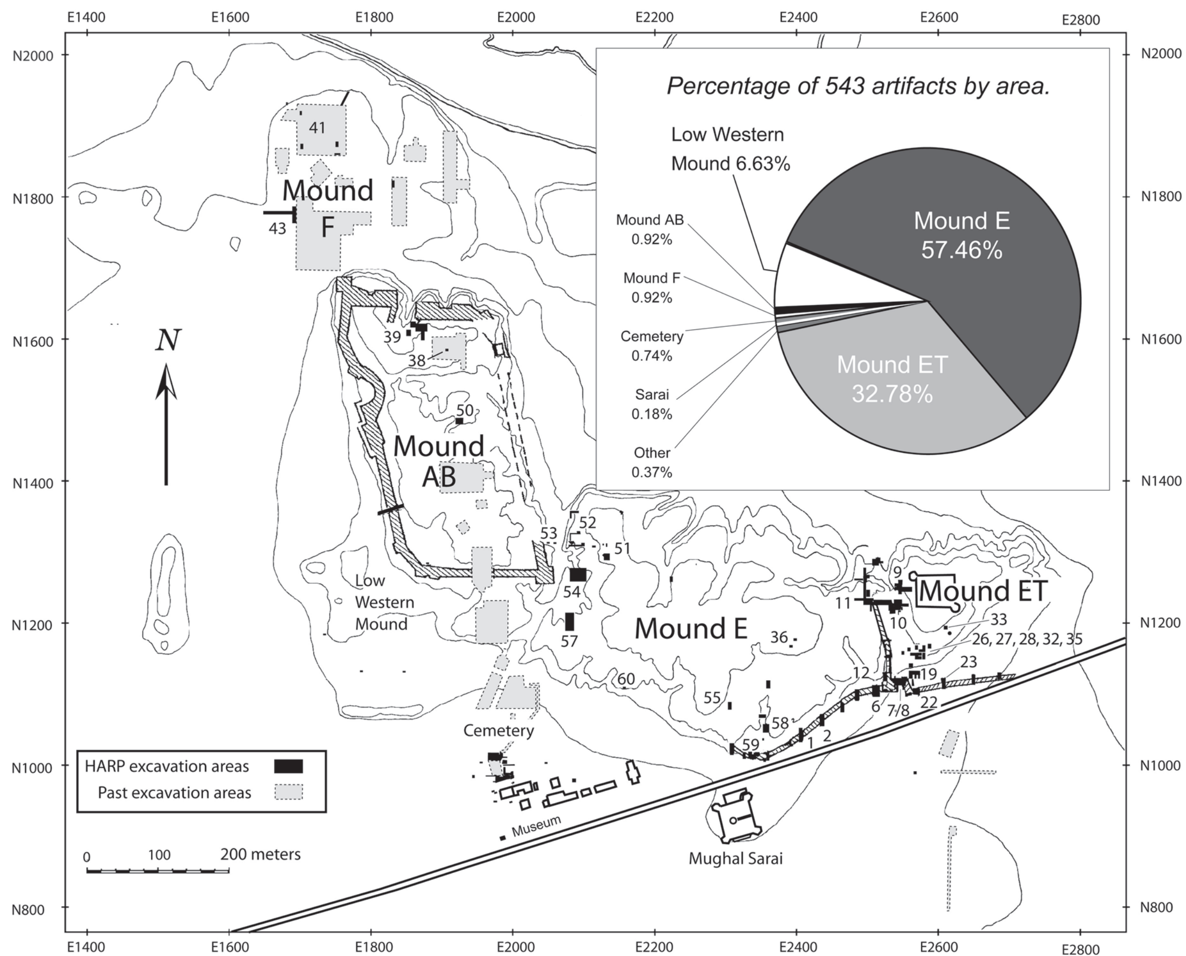



**Figure 9.15** Vesuvianite-grossular artifact distribution at Harappa.
Vesuvianite-grossular artifacts have been recovered in all trenches and areas labeled on this site plan.

was found on the floor of a Late Harappan (Period 5) structure (Trench 38, Mound AB). It is possible that this artifact was initially deposited there during Period 5. However, not far away was found a small pot containing mixed beads, amulets, stone fragments and metal scraps (Meadow *et al* 1996: 5-6, figures 34-36). This find is thought to probably represent the cache of some Late Harappan person who gathered miscellaneous objects from the surface of the site during that period (ibid.: 6; Kenoyer *personal communication*). The vesuvianite-grossular flake found nearby might, therefore, be a loose item from an earlier phase that was collected and brought to this location.

When the spatial and temporal distributions of vesuvianite-grossular artifacts at Harappa are considered together, we see that the four examples from Period 3B levels were all recovered on mounds E and ET (in trenches 9, 10 and 11). Nearly 98% of all examples from Period 3C (170 of 174) also come from those two conjoined mounds. The four artifacts from that period that do not, were recovered on Mound F (n = 3 in trenches 41 and 43) and beneath the Mughal Sarai (n = 1). The two remaining vesuvianite-grossular artifacts of the 180 from secure contexts are the individual flakes from periods 1 and 5 on Mound AB discussed in the preceding paragraph.

I have provided this detailed discussion of the spatial and temporal breakdown of Harappa's vesuvianite-grossular sub-assemblage because I wish to highlight what I believe to be two *genuine* patterns (see Appendix 9.9) related to the use of this stone at the site. Firstly, it appears that Harappan beadmakers probably only used vesuvianite-grossular to create

**Figure 9.16** Spatial distribution of all vesuvianite-grossular and "Ernestite" artifacts at Harappa

| **Vesuvianite-Grossular** (n = 543) | | | | | **"Ernestite"** (n = 75) | | |
|---|---|---|---|---|---|---|---|
| *debris* | *unfinished beads* | *finished beads* | *amulets* | **Mound E-ET** | *drills* | *blocklets / blanks* | *debris* |
| 2 | | | | Trench 1 | 1 | | |
| 3 | | | | Trench 2 | | | |
| 1 | | | | Trench 6 | | | |
| 1 | | | | Trench 7 | 1 | | |
| 2 | | | | Trench 8 | | | |
| 1 | | | | Trench 9 | | | |
| 10 | 1 | | | Trench 10 | 1 | | 3 |
| 2 | | | | Trench 11 | 1 | 1 | 2 |
| 2 | | | | Trench 12 | | | |
| 24 | | | | Trench 19 | 1 | | |
| 2 | | | | Trench 22 | 1 | | |
| 7 | | | | Trench 23 | | | |
| 13 | | | | Trench 26 | | | |
| 37 | 1 | | | Trench 27 | 3 | | 5 |
| 31 | 1 | 1 | | Trench 28 | 7 | 1 | 4 |
| 8 | | | | Trench 32 | 2 | | |
| 1 | | | | Trench 33 | | | |
| 3 | | | | Trench 35 | | | |
| 235 | 4 | | | Trench 36 | 2 | 3 | 9 |
| 5 | | | | Trench 51 | | | |
| 2 | | 1 | | Trench 52 | | | |
| 1 | | | | Trench 53 | | | |
| 5 | | | | Trench 54 | | | 3 |
| 1 | | | | Trench 55 | | | |
| 3 | | | | Trench 57 | | | 1 |
| 4 | | | 1 | Trench 58 | | | |
| 3 | | 1 | | Trench 59 | | | |
| | | 1 | | Trench 60 | | | |
| 67 | 1 | 1 | | Survey on E/ET | 6 | 1 | 8 |
| | | | | **Mound AB** | | | |
| 1 | | | | Trench 38 | | | |
| 3 | | | | Trench 39 | | | |
| | 1 | | | Trench 50 | | | |
| | | | | Survey on AB | | | 4 |
| | | | | **Mound F** | | | |
| | 1 | | | Trench 41 | | 1 | |
| 3 | | | 1 | Trench 43 | | | |
| | | | | **Other** | | | |
| 1 | | | | Mughal Sarai | | | |
| 4 | | | | Cemetery area | | 1 | 1 |
| 34 | | 2 | | Low Western Mound | | | 1 |
| | | 2 | | Unknown (Harappa Museum) | | | |
| *522* | *10* | *9* | *2* | *TOTALS* | *26* | *8* | *41* |

ornaments during periods 3B and 3C. Secondly, it also seems that this activity was almost exclusively confined mounds E and ET during those periods. Admittedly, these patterns could be due, at least in part, to bias stemming from both excavation strategies and physical aspects of the site (discussed in Chapter 4). Recall Figure 4.11. Almost 90% and 80% of all rock and mineral artifacts representing periods 3B and 3C (respectively) were recovered from mounds E and ET. Those phases are, quite obviously, over-represented in the assemblage of stone and metal artifacts from secure contexts. However, every square meter of Harappa's surface has been surveyed by the HARP and this has provided us with a good and

**Figure 9.17** Temporal distribution and shared lot association of all vesuvianite-grossular and "Ernestite" artifacts from stratigraphically secure contexts at Harappa (np = not present).

| ***Period*** | ***1*** | ***2*** | ***3A*** | ***3B*** | ***3C*** | ***4/5*** | ***Shared secure lots (n=11)*** |
|---|---|---|---|---|---|---|---|
| **Vesuvianite-Grossular** (n = 180 in 77 lots) | 1 | *np* | *np* | 4 | 174 | 1 | 14.3% of secure lots containing vesuvianite-grossular also contain "Ernestite" |
| **"Ernestite"** (n = 40 in 34 lots) | *np* | *np* | *np* | 2 | 38 | *np* | 32.4% of secure lots containing "Ernestite" also contain vesuvianite-grossular |

**Figure 9.18** Spatial distr bution of all vesuvianite-grossular and "Ernestite" artifacts from non-secure contexts at Harappa.

| ***Mound*** | ***F*** | ***AB*** | ***E*** | ***ET*** | ***Low Western*** | ***off-mound / unknown*** |
|---|---|---|---|---|---|---|
| ***vesuvianite-grossular*** *artifacts* (n = 363) | 2 | 2 | 212 | 106 | 36 | 5 |
| *percent of total* | 0.55% | 0.55% | 58.4% | 29.2% | 9.9% | 1.4% |
| ***"Ernestite"*** *artifacts* (n = 35) | 1 | 4 | 18 | 11 | 1 | 0 |
| *percent of total* | 2.9% | 11.4% | 51.4% | 31.4% | 2.9% | 0% |

representative conception of where major and minor craft activities took place at the site (Kenoyer and Miller 2007; Miller 1994a, 1997, 2000). Figure 9.18 shows the spatial distribution of vesuvianite-grossular artifacts recovered during surveys in combination with those from other non-secure contexts such as brick-robber trenches (this amounts to 363 artifacts in total). The vast majority (87.6%) of such artifacts were found, once again, on mounds E and ET indicating that the most intensive working of that stone took place in that area. Most of the remaining ones (9.9%) came from the Harappan Period dump called the Low Western Mound. If a significant amount of vesuvianite-grossular bead-making activity had taken place on mounds F or AB then the amount of debris recovered from non-secure deposits in those areas should have been far greater than a mere two flakes from each mound.

The spatial patterning of vesuvianite-grossular artifacts at Harappa strongly suggests that the acquisition of that stone and the production of ornaments using it were activities almost exclusively engaged in by residents of mounds E and ET. The reason for this might be because the procurement and distribution of this important resource was something that was closely controlled by individuals or groups living in those areas. On the other hand, it may be the case that, as I will argue shortly, beadmakers in those areas were the only ones who possessed (controlled) the technology needed to perforate this very hard variety of stone. Perhaps both explanations are true.

The spatial patterning of vesuvianite-grossular artifacts also provides another important line of evidence indicating that a close relationship existed between the peoples living and working on mounds E and ET. Recall that in Chapter 4 I showed that grindingstone source usage patterns in those adjoining areas of the site more or less paralleled one another throughout periods 3B and 3C and in surface collections. Below, I show that the same is true for "Ernestite." In the next chapter, I present evidence suggesting that peoples in those areas were

the exclusive producers and/or users of alabaster bangles during Period 3. Considered together, these comparable synchronic patterns lend support to the interpretation that residents of mounds E and ET were probably a part of the same socio-political entity. When those two areas are regarded as a single mound (E-ET) and compared to the other mounds at Harappa, an affirmative answer is provided to study's third line of inquiry.

The chronological distribution of vesuvianite-grossular artifacts at Harappa clearly shows that the most intensive and, perhaps, exclusive period of acquisition and use of this stone was during the latter part of the Harappa Phase (for reasons already explained, the single flakes found in Ravi and Late Harappan levels *may* be anomalous items that were not originally acquired during those phases). This pattern could indicate that sources were not accessible (either directly or indirectly) to the site's residents prior to that time. Toward the end of the third millennium BC (ca. Period 3C at Harappa), the stone *might* have been acquired indirectly through interaction with Bactria-Margiana Complex (BMAC) peoples of southern Central Asia who were then expanding from that region into the west-northwestern borderlands of South Asia (Hiebert and Lamberg-Karlovsky 1992; Jarrige 1991a) and were evidently present in some capacity at Indus Civilization cities (Meadow 2002; Parpola 2005). As I showed in Chapter 7, the black steatite that was used to carve the small "BMAC-like" wig found in Period 3C levels on Mound F at Harappa appears to be most closely related to steatite occurring in the same geologic formation as one of the vesuvianite-grossular sources examined in this chapter – the Sakhakot-Qila ophiolite. That formation is located on the northern fringe of the Peshawar Valley nearby the Khyber Pass going west into Afghanistan and the Malakand Pass going north into the Swat Valley. If Indus Civilization peoples used these particular passes when traveling to and from the Harappan outpost of Shortughaï in northern Afghanistan then they themselves might have had direct access to vesuvianite-grossular from the Sakhakot-Qila ophiolite.

Regarding the possibility that vesuvianite-grossular sources were not accessible until latter part of the Harappa Phase, I would point out, again referring to Chapter 7, that the site's residents appear to have been acquiring steatite from deposits in the general vicinity (in the Hazara District and the Khyber Agency) of the Sakhakot-Qila area since the Early Harappa Period. Early Harappans had settlements (Sarai Khola and nearby Hathial) near the eastern edge of the Peshawar Valley and, as indicated by finds at Ghalegay Rock Shelter (Stacul 1987), had at least limited interaction (probably via the Malakand Pass) with peoples in the Swat Valley. The single vesuvianite-grossular flake from Period 1 levels at Harappa (which, of those analyzed, is one of the most geochemically analogous to the Sakhakot-Qila source) might, therefore, have actually been acquired at that time. However, it would have been impossible for Ravi Phase beadmakers to perforate a stone of its hardness using the chert and jasper drills that they then possessed. I believe that this technological limitation is one of the main reasons why vesuvianite-grossular really does not appear in Harappa's archaeological record until the latter part of Period 3.

The only material in Harappa's rock and mineral assemblage from which drills capable of perforating vesuvianite-grossular could have been fashioned was "Ernestite" (support for this statement is provided in Appendix 4.5). To date, 75 artifacts composed of that stone (drill bits, worked blocklets / drill blanks and debris) have been recovered. Their spatial distribution is shown in the last three columns of Figure 9.16. In *all* trenches and areas where "Ernestite" artifacts were recovered vesuvianite-grossular artifacts were also found. When association at the level of shared stratigraphically secure excavation lot is considered (Figure 9.17 far right column), we see that in roughly

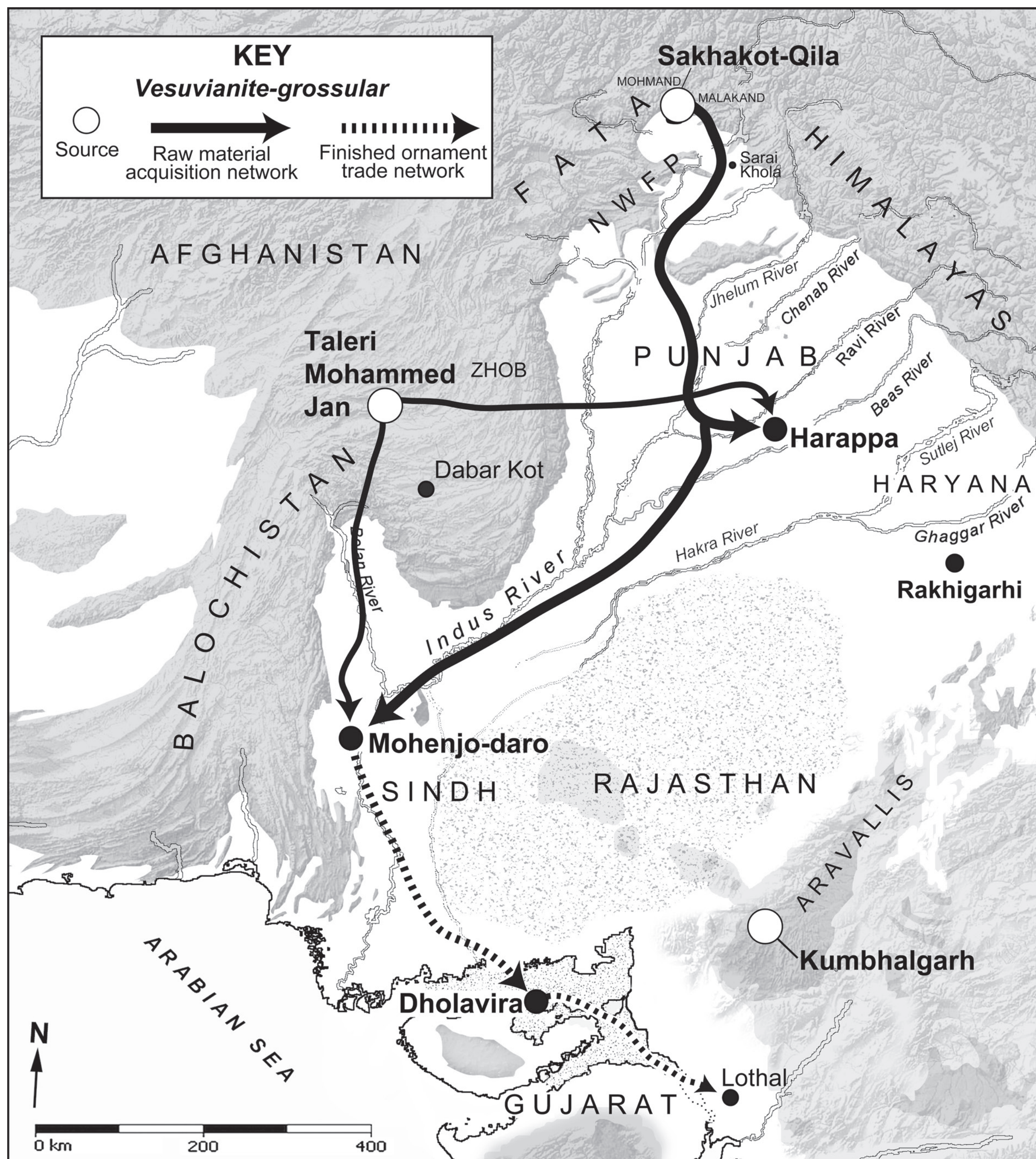



**Figure 9.19** Harappan vesuvianite-grossular acquisition and trade networks (provisional).

one out of every three lots (32.4%) in which an "Ernestite" artifact was recovered a vesuvianite-grossular artifact was also present. The 40 "Ernestite" artifacts from secure contexts all come from periods 3B (n = 2) and 3C (n = 38) levels (Figure 9.17 bottom row) on Mound E/ET. Nearly 83% of the 35 examples from non-secure contexts are also from that area (Figure 9.18 bottom row).

The spatial and temporal distribution patterns of "Ernestite" and vesuvianite-grossular artifacts at Harappa are practically mirror images of one another. This is almost certainly no coincidence. Vesuvianite-grossular could not have been drilled without the use of "Ernestite" bits (holes can be "pecked" through that stone to make very small beads but there is no evidence this was done). Harappans might have had access to the regions where vesuvianite-grossular occurred and even knowledge of the stone's existence as early as the Ravi Phase but they did not then possess the technology needed to turn it into finished

beads. That each variety of stone appears in the archaeological record at exactly the same time when (ca. periods 3B and 3C) and, largely, in the same places where (Mound E/ET) beadmakers were using the other one should come as no surprise. In Chapter 13, I discuss the implications of the differential distribution of this and other rock varieties at Harappa.

## CHAPTER CONCLUSION

As early as the Ravi Phase (Period 1), residents of Harappa acquired vesuvianite-grossular from sources along the northwestern fringe of the Peshawar Valley (today the Mohmand-Malakand regions of the FATA). However, it was not until the middle to late part of the Harappa Phase (periods 3B and 3C) that site residents (mainly those dwelling on mounds E and ET) began to import raw material from that area, as well as from another source in northern Balochistan, in abundance. The reason for this likely has to do the development of a specialized drilling technology that permitted them to make ornaments from this variety of stone, which was much harder than the other rock and mineral varieties they typically used. Bead-makers at Mohenjo-Daro in Sindh evidently began to import vesuvianite-grossular from the FATA and Balochistan to make ornaments during approximately the same period.

I am currently conducting large-scale examinations of the rock and mineral artifact assemblages at the Indus Civilization settlements of Dholavira and Lothal in Gujarat and Rakhigarhi in Haryana. I have not yet encountered vesuvianite-grossular artifacts of any kind among the Rakhigarhi materials. However, finished ornaments composed of high-quality clear, largely fracture-free vesuvianite-grossular have been recorded (and preliminarily confirmed to be that material using specific gravity testing) at both Dholavira and Lothal. Significantly, no flakes or fragments of this stone have yet been observed within the large assemblages of ornament manufacturing waste recovered from those sites. It is, therefore, my provisional conclusion that vesuvianite-grossular ornaments are items that were made mainly or exclusively at Harappa and Mohenjo-Daro. The finest-quality finished examples were then traded to settlements like Dholavira and Lothal. Figure 7.19 is a map depicting these provisional vesuvianite-grossular acquisition and trade networks.

In the next chapter, I examine the acquisition of alabaster – a much more widely available variety of stone that was used to create both small ornaments and, on occasion, very large objects.

# CHAPTER 10

# ALABASTER ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: THE DIFFERENT FORMS OF GYPSUM AT INDUS CIVILIZATION SITES

The mineral gypsum – hydrated calcium sulfate ($CaSO_4 \bullet 2H_2O$), is found in many forms at Indus Civilization sites. Transparent tabular crystals known as selenite have been recovered at Harappa (recall Figure 4.4 C). Gypsum mortar was sometimes used at the site (Vats 1940: 12-13), as well as at Mohenjo-daro (Mackay 1938: 162), for the "pointing" (filling the joints) of brick masonry. At Dholavira, the inlayed lettering of what appears to have been a large signboard was composed of a heated gypsum paste (R.S. Bisht personal communication 2004). Naturally precipitated gypsum has been found encrusting artifacts at Mohenjo-daro (Mackay 1938: 162, 525) and in the soils around Harappa (Amundson and Pendall 1991: 18). The white coating on the exterior of pots in some burials at Harappa, which some believe to be deliberately applied gypsum plaster (Strahan 1991), may actually be natural encrustations. In this chapter, I identify the sources from which residents of Harappa acquired the massive variety of gypsum known as alabaster.

The name "alabaster" has been used to describe ornamental stones of varying chemical compositions. "Oriental" or "Egyptian" alabaster is actually travertine – calcium carbonate ($CaCO_3$) and is sometimes also called "onyx marble" (el-Hiwanni and Loukina 1972; Webster 1958). Recall the small stone ring (Figure 4.7 B) mentioned in Chapter 4 that looks much like the travertine quarried today in the Chagai Hills of Balochistan (Ahmad 1975: 124-128). This is not the type of material that is under examination here. Genuine alabaster is the compact, massive form of gypsum. Gypsum alabaster (hereafter just alabaster) is semi-translucent in thin pieces and has a sugary texture that becomes satiny when polished. Purer varieties are white to pink in color. These qualities, along with the fact that it is a relatively common and easily carved stone (Mohs hardness of 2), made it a popular ornamental material in many areas of the ancient world (Rapp 2002: 123-127). The Indus Civilization was no exception. A wide range of alabaster objects have been found at Indus settlements including large and small rings, whorls, mace-heads, bangles, beads, cubical weights, discs, balls, inlays, pendants, "gamesmen", lattice-screens, plugs, bowls and bottles (see Lahiri 1992 for a site by site listing of alabaster artifacts).

Gale and others (1988) successfully employed a combination of sulfur isotope and strontium isotope analysis to determine the geologic provenience of alabaster artifacts from Mycenaean Greece. Using these same methods, a set of alabaster objects from Harappa is compared to geologic samples from multiple locations in three potential source formations surrounding the Indus Valley. This study is supplemented with isotopic analyses of a small set of artifacts from three other Early Harappan and/or Harappan period sites as well as with the characterization of an unusual type of quartz recovered at Harappa, which may derive from one of the alabaster sources under consideration. Before presenting the details of those studies, I first provide an overview of the forms and contexts in which alabaster is found at the site of Harappa.

**Figure 10.1** Alabaster artifacts excavated by the Harappa Archaeological Research Project (1986-2001).

| CONTEXT | *Mound AB* | *Mound F* | *Mound ET* | *Mound E* | *Cemetery* | *Sarai* | *Other* | *total* |
|---|---|---|---|---|---|---|---|---|
| **surface or disturbed** | 106 | 9 | 10 | 69 | 1 | 2 | 13 | *210* |
| **Period 3C** | 38 | 46 | 38 | 46 | 8 | 3 | . | *179* |
| **Period 3B** | 1 | . | 12 | 4 | 1 | . | . | *18* |
| **Period 3A** | 3 | . | 1 | 5 | . | . | . | *9* |
| **Period 2** | 3 | . | . | . | . | . | . | *3* |
| **Period 1** | 3 | . | . | . | . | . | . | *3* |
| **total** | *154* | *55* | *61* | *124* | *10* | *5* | *13* | ***422*** |
| **objects / debris** | 81 / 73 | 24 / 31 | 31 / 30 | 54 / 70 | 3 / 7 | 0 / 5 | 7 / 6 | 200 / 222 |

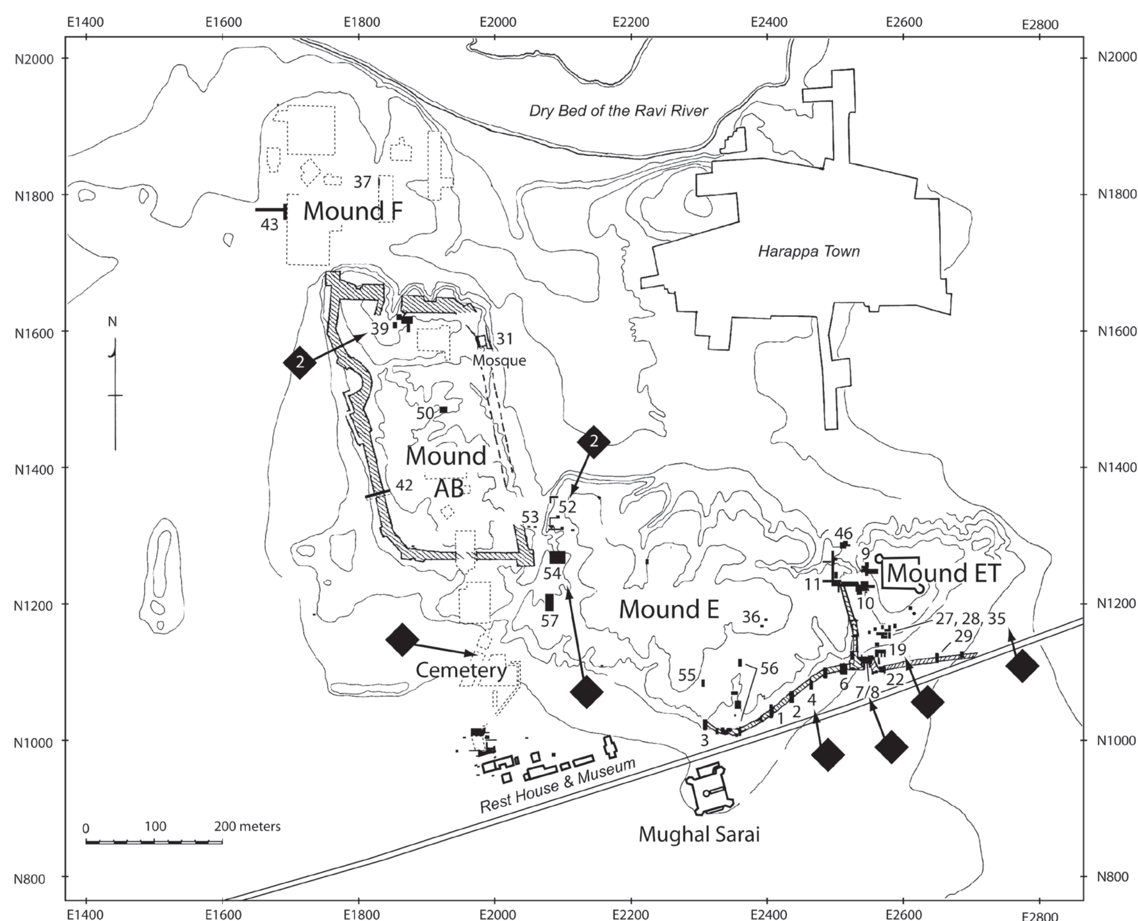



**Figure 10.2** Mounds, areas, and trenches (in bold) where alabaster objects or fragments of manufacturing debris have been recovered. Diamond shapes and arrows denotes trenches/areas where "Mari Diamonds" were found.




**Figure 10.3** Alabaster debris and non-diagnostic fragments from Harappa.

## ALABASTER AT HARAPPA

Alabaster is one of the most abundant of the minor rock and mineral varieties in Harappa's lithic assemblage. To date, 422 artifacts made from this stone have been recovered during excavations by the HARP (Figure 10.1). Numerous other examples were described in the original excavation report (Vats 1940). More than half (n=222) of this material sub-assemblage consists of manufacturing debris or non-diagnostic fragments (Figure 10.3). It is, therefore, reasonable to assume therefore that many or most of the finished alabaster objects recovered at Harappa were crafted at the site itself. An assortment of these artifacts (including several that were analyzed for this study) are displayed in figures 10.4 A through C. Although most alabaster artifacts at Harappa have weathered exteriors, cracks and fractures exposing the interior reveal that the material preferred by Harappans tended to be compact, fine-grained and sugary white. A few fragments (but no artifacts) with a pink cast have also been found.

Alabaster objects and debris fragments have been recovered from all major areas of the site (figures 10.1 and 10.2) and from every chronological phase and sub-phase from Period 1 through Period 3C. Although no examples were found during the very limited excavations of Period 4 and 5 levels, approximately half of the assemblage (n=210) consists of surface finds and so it is possible that some of those artifacts may have originated in Late Harappan strata that were subsequently disturbed by brickrobbers. The great majority (179 of 212 or 85%) of the alabaster artifacts from secure stratified contexts belong to Period 3C. This then is the optimal assemblage with which to examine site-wise synchronic variation in the utilization of alabaster. Next I discuss how that material was distributed across the site during Period

**Figure 10.4** An assortment of alabaster artifacts from Harappa. Those noted with artifact numbers were analyzed for this study.




**A**. Clockwise from top-left: alabaster rings, whorl, ball, bangle fragments, pendent (H94/4999-511), dish fragment, small vessel.



**B**. Cubical weight made of alabaster from Vats' excavations (#13799).




**C**. Large alabaster ringstone fragment (H98/7715-9) from Period 3C levels on Mound AB, Trench 42.

3C. Later in this chapter I examine if resident/craftspeople living in different parts of the site at this time used alabaster from the same sources.

In general, there does not appear to have been a great deal of intra-site variation in the use of alabaster as a raw material during Period 3C. Manufacturing debris is found in those levels on every mound at Harappa as well as from the 3C deposits beneath the Mughal era (16th to 18th centuries AD) caravanserai south of Mound E. People residing and working in different areas of the city were basically making or acquiring the same types of alabaster

objects. Certain artifacts, such as the cubical weight pictured in Figure 10.4 B and the large ringstone fragment pictured in Figure 10.4 C, are exceptionally rare or unique and thus found only in a few locations. More common items, however, such as beads, inlays and vessels tend to be found in most areas of the site. There is one striking exception. Although fairly common (making up around 18% of finished alabaster artifacts), alabaster bangles have only been found on mounds E-ET, which would indicate that residents of those areas were the only ones producing and/or consuming that particular type of item. This may very well be a diachronic pattern. Even though the alabaster assemblages for periods prior to 3C are significantly smaller (and thus subject to greater sampling bias), during periods 3A and 3B bangles made of this alabaster are also found only on mounds E-ET.

Twenty-nine alabaster artifacts from Harappa were selected for isotopic analysis (Appendix 10.1). This amounts to approximately a seven percent sample of this material sub-assemblage. The set included artifacts from each of Harappa's habitation mounds and each phase and sub-phase between periods 2 and 3C. Most of those chosen (19 of 29) were non-diagnostic manufacturing debris fragments. The remaining ten samples were taken from both common alabaster objects (bangles and vessels) and important varieties of rare ones (a ringstone and a cubical weight). In the following section I discuss the geologic sources to which these artifacts were compared.

## POTENTIAL SOURCES OF HARAPPAN ALABASTER

There are extensive deposits of alabaster in several regions surrounding the Indus Basin that would have been directly accessible to Indus Civilization peoples. In this section, I discuss deposits in the three regions that were closest to Harappa – the Salt Range, the Sulaiman Range and Kohat (Figure 10.5). Samples from multiple locations within each of these areas were collected and analyzed for this project. Sources in several other regions are also noted that, although not yet analyzed, are important to be aware of when considering the results of the isotopic studies. Before discussing the potential sources of Harappan alabaster, however, I want to first make it clear that there are certain parts of the Greater Indus region where that material is almost certainly not to be found.

### Gypsum occurrences that are not alabaster sources

Gypsum is a mineral precipitate that forms in environmental settings (generally arid ones) in which the evaporation of water takes place (Eckhardt 2001; Warren 1989: 14). Those settings may be terrestrial (such as inland seas or lakes) or marine (typically shallow, marginally restricted oceanic basins). Gypsum is the most common of the sulphate minerals (Deer *et al*. 1992: 615) and occurrences of some kind or another can be found in most parts of the Greater Indus region (Bender 1995b: 264-265; Wadia 1975: 467). The alabaster variety, however, is much less widespread. Just because a large gypsum deposit is reported to occur in a certain area does not necessarily mean that alabaster are also found there. This is a fact that has sometimes not been adequately recognized when considering the potential sources of that material.

#### *Indus Alluvium/Thar Desert*

When outlining the raw material resources available to Indus peoples in the Sindh region, Nayanjot Lahiri noted in the section on "Alabaster" that "thick beds of gypsum are abundant in the Indus alluvium" (Lahiri 1992: 24). Although this is indeed so, the gypsum of terrestrial origin that occurs within the alluvium of the Indus Basin is most definitely not of the alabaster variety. Rather, it is either the selenite

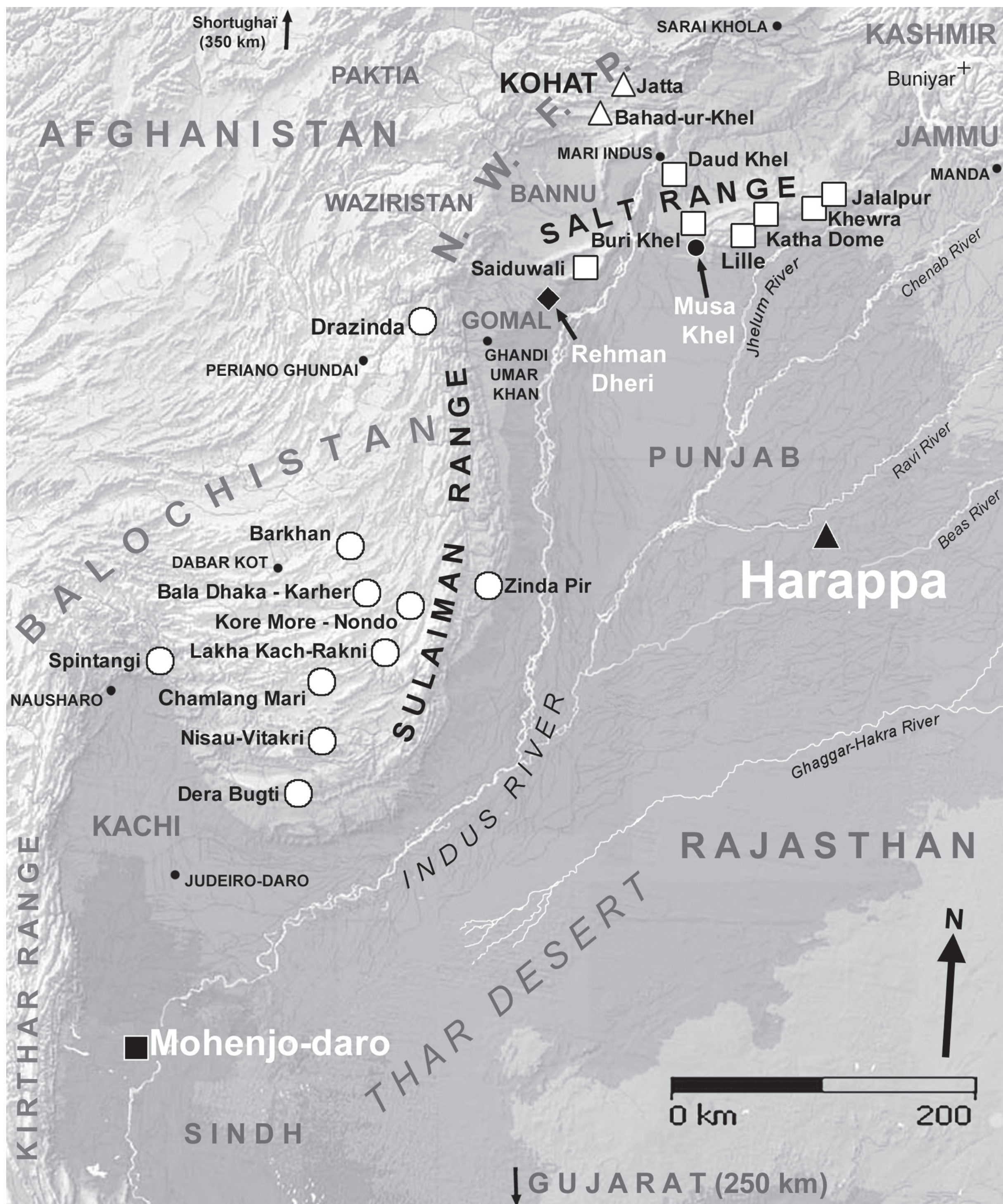



**Figure 10.5** Regions, sources and sites discussed in this chapter.

or the gypsite (massive but impure gypsum mixed with sand and clay) varieties that are found in thick beds just below the alluvium (Figure 10.6) in areas like Thar Desert. Such deposits are mined today in the Bahawalpur District of Pakistan (Ahmad 1969: 92) and all throughout west-northwestern Rajasthan (Deb 1952; Geological Survey of India 2001b: 68-70; Jacob *et al*. 1952).

*Western Sindh*

It has been suggested that the Harappans of Mohenjo-daro may have obtained alabaster from the nearby Kirthar Range of western Sindh (Lahiri 1992: 24; Pascoe 1931: 679; Ratnagar 2004: 151). This would not have been possible, however, as it is selenite and veins of fibrous gypsum, rather than massive compact alabaster, which occurs in the Tertiary shales



**Figure 10.6** Quaternary gypsite deposit immediately below the desert alluvium, Bikaner district, western Rajasthan.




**Figure 10.7** Alabaster lattice fragments on display at the Mohenjo-daro museum.

of this region (Ahmad 1969: 92). The low grade gypsum of the Kirthar Range is mined today for use in the cement industry (Hunting Survey Corporation 1960: 447; Jafry and Ahmad 1991: 28-30) but would have not at all been suitable for carving the types of artifacts being examined in this chapter. In spite of that, raw material of this kind may still have had value to ancient residents of Sindh. For example:

Nineteenth century craftsmen in Sindh used gypsum from deposits in the Kirthar Range for "casting lattices and open work for the tops of doors and windows, and for other purposes [where] the partial admission of air is desirable" (Buist 1852: 229). Interestingly, fragments of stone lattices that are thought to have served the same purpose have been found at Mohenjo-daro (Sahni 1931b: 219). Although those objects appear to have been cut or carved from alabaster blocks, it is difficult to tell for certain if this was so because they have heavily weathered exteriors (Figure 10.7). A closer examination of those artifacts might reveal that they were cast from a gypsum plaster instead. This does not mean that alabaster was not used at Mohenjo-daro. On the contrary, many objects that are clearly made of this variety of gypsum have been recovered at the site. It is highly unlikely, however, that the raw stone used to fashion them came from the Kirthar Range. Dr. Massimo Vidale kindly supplied a single small sample from an alabaster vessel fragment found in the area DK at Mohenjo-daro during the surface surveys by the IsMEO-Aachen University project (Pracchia *et al*. 1985). Analysis of this sample will hopefully allow us to determine what region residents of that site were obtaining that material from.

***Gujarat***

The Indian state of Gujarat has also been noted as a possible alabaster source for Indus Civilization peoples (Lahiri 1992: 106; Pascoe 1931: 679). Although extensive gypsum deposits do occur in many



**Figure 10.8** A mass of selenite crystals from the Little Rann of Kutch, Gujarat.

districts (especially Kutch and Junagadh), a review of the geologic literature indicates that they are not found in the form of alabaster (Desai 1973; Geological Survey of India 2001a: 66-67; Krishnaswamy 1979: 249-250; Sinha 1967: 300-301). Instead it is selenite crystals, such as those that form in the shallow ranns, which occur there (Figure 10.8).

If selenite or gypsite was used to make the mortars, plasters and pastes found at some Indus Civilization sites then those materials could have come from any of the regions discussed above. The alabaster used to make objects like those found at Harappa could not have, however. Next we examine several of the regions where high quality alabaster does occur.

### The Salt Range

The Salt Range lies on the northern edge of the Punjab Plain, approximately 225 km away from Harappa at its closest point. Beds of massive alabaster gypsum up to 100 meters thick in some instances are exposed at various places along the base of these mountains (figures 10.9 and 10.10). There has long been a local industry devoted to carving plates and other items from Salt Range alabaster (Wynne 1878: 300; Pascoe 1931: 679; Habib 1986: 13, Map 4B). Geologic samples were acquired from seven sources stretching from the eastern to the western margins of the range (identified with white squares in Figure 10.5). The five easternmost of these deposits occur within the Salt Range Formation (Alam and Khan 1982). Although its precise age has been debated (Gee 1945; Ghosh *et al.* 1951; Shah 1977: 4), today the Salt Range Formation is generally considered to span the late-Precambrian to Cambrian eras (ca. 600 to 500 m.y.a.) (Kazmi 1995c: 66-68; Shah 1980: 8). When referring to deposits associated with this formation I use the term Infra-Cambrian, which denotes the period immediately preceding the Cambrian (Palmer 1977). The two westernmost Salt Range alabaster

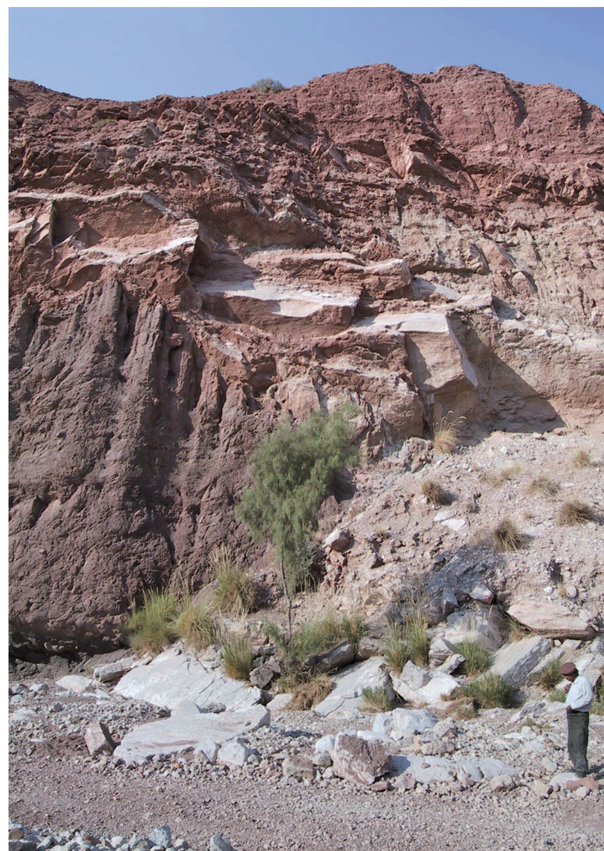


**Figure 10.9** Massive alabaster gypsum beds at Buri Khel, central Salt Range.



**Figure 10.10** Massive alabaster gypsum beds at Saiduwali Nala, western Salt Range (Khassor Range).

deposits sampled for this study (Daud Khel and Saiduwali Nala) are marine in origin and occur in the Sakesar Formation of Eocene age (ca. 55 to 34 m.y.a.) (Kazmi 1995c: 112; Kazmi and Jan 1997: 478).

Alabaster from the Salt Range would have been most directly accessible to Indus Civilization peoples during the Kot Dijian phase (Period 2 at Harappa). In recent years several Kot Dijian sites have been located in the central to eastern part of the range (Dar 2002). The small Kot Dijian/Harappan settlement of Musa Khel (Dani 1971: 32) lies roughly 15 km southeast of the Buri Khel alabaster deposit. Fragments of alabaster were evident on the site's surface along with other lithic materials from the Salt Range including black chert (Chapter 6), limestone and laterite. Small samples for analysis were taken from two such fragments collected by Dr. Syed Baqri of the Pakistan Museum of Natural History during our fieldwork in the area. Alabaster fragments were also observed (and one sampled) on the surface of the Early Harappan Period site of Rehman Dheri (Durrani 1988), which lies just over 30 km southwest of the Saiduwali Nala.

### The Sulaiman Range

Two hundred twenty kilometers directly west of Harappa is the north-south running Sulaiman Range. The extensive alabaster deposits located in these mountains (identified with white squares in circles 10.5) are mainly concentrated in the wide southern portion of the range known as the Sulaiman Lobe. Zinda Pir, the easternmost of these southern sources, lies in the Dera Ghazi Khan District of Punjab Province. The alabaster found at this deposit and others nearby is described as gray to grayish white in color (Hussain and Mustafa 1970). The remaining Sulaiman Lobe area deposits are situated in Balochistan proper. The geologist W.T. Blanford visited alabaster occurrences in the vicinity of Dera Bugti and described the material there as "perfectly pure white in color, and quite as well adapted for



**Figure 10.11** Massive alabaster gypsum beds at Bahad-ur-Khel, Kohat District, NWFP.

ornamental purposes" (Blanford 1883: 127). Alabaster is also found in the far north of the Sulaiman Range around Drazinda in the NWFP. All of the Sulaiman deposits are marine evaporites that occur within either the Baska or the Domanda formation, which are both of Eocene age (Malkani 2000). Mr. M. Sadiq Maklani of the Geological Survey of Pakistan–Quetta generously provided a set of alabaster samples for isotopic analyses from the ten Sulaiman Range locations identified in Figure 10.5.

The alabaster artifacts found at Harappa could easily have been derived from any of the Sulaiman Range sources. Drazinda, the northernmost of the deposits, lies near the natural route between Early Harappan and Harappan Periods sites on the Gomal Plain like Ghandi Umar Khan (Khan *et al.* 2000) and those of northern Balochistan such as Periano Ghundai (Fairservis 1959: 329). Indus Civilization peoples at sites on the Kachi Plain such as Nausharo (Jarrige 2000) and Judeiro-daro (Flam 1981: 251-53) as well as those living at highland settlements like Dabar Kot (Fairservis 1959: 289) would have been best positioned to access the rich alabaster deposits of Sulaiman lobe region. Although the alabaster found at Zinda Pir does not appear to be the same sugary white variety that was used to make artifacts at Harappa, this source would have nonetheless been the closest and most directly accessible to residents of that site.

### Kohat

The Kohat district, NWFP is located directly northwest of the Salt Range. Although the massive gypsum of marine origin that occurs in this region is frequently mixed with clay that gives it a greenish cast, purer beds of white material (Figure 10.11) are often found (Rashid *et al.* 1965: 4-7; Wynne 1875: 45). Samples of relatively pure alabaster from two deposits – Jatta and Bahad-ur-Khel (identified with white triangles in Figure 10.5), were kindly provided

by Dr. Syed Baqri of the Pakistan Museum of Natural History in Islamabad. Both of those locations occur within the Jatta Gypsum Formation of early Eocene age (Bender 1995b: 264; Fatmi 1974: 53-54).

It is important to consider alabaster from the Kohat region in a study such as this even though there would have been closer sources of purer material to Harappa. These deposits lie between 40 and 80 km northeast of the series of Early Harappan sites in the Bannu Basin (Khan *et al.* 1991a). Some of this material might conceivably have come to Harappa through interaction with related groups in that region.

### Other potential alabaster sources

There are several other regions from which the alabaster recovered at Harappa could have been obtained other than, or in addition to, the three discussed above. Although sources in the areas below have not yet been analyzed, it is important to take into account their locations and geologic contexts when later evaluating the results of the isotopic studies. Because some of those areas are located on or near what would have been the northern fringes of the Indus Civilization, several do not fall within the area of Figure 10.5.

#### *Afghanistan*

The presence of the Harappan outpost of Shortughaï (Francfort 1984b) in the far north of Afghanistan (not pictured on Figure 10.5) opens the possibility that alabaster from deposits between that area and the Indus Valley may have been brought to Harappa. One potential source of upper Jurassic age (ca. 160 to 145 m.y.a.) is found in the vicinity of Dudkash in Baghlan Province (ESCAP 1995: 58). This occurrence lies near a major route to northern Afghanistan through the Hindu Kush. Other potential sources are found within Cretaceous formations (ca. 145 to 65 m.y.a.) in the west-northwestern part of the country (Wolfart and Wittekindt 1980: 421) and Eocene-age formations along the eastern border with Pakistan (Ludington *et al.* 2007: Figure 16).

#### *Hazara (NWFP)*

Lying less that 100 km northeast of the Early Harappan site of Sarai Khola (Halim 1972) in the Hazara District, NWFP, are beds of white calcareous gypsum 15 to 200 meters thick that occur within the Hazara Formation (Ali *et al.* 1964: 36-37). Although originally correlated with the Infra-Cambrian Salt Range Formation of the Punjab, radiometric dating has indicted that the Hazara Formation, which has undergone low-grade metamorphism, is probably older (Kazmi 1995c: 72). Of all of the uncharacterized alabaster sources, this one is especially important due to the fact that much of the steatite found at Harappa appears to be coming from this region (see Chapter 7).

#### *Jammu and Kashmir*

Alabaster deposits in Jammu and Kashmir are especially significant too because, as we shall see in Chapter 12, many of the lead artifacts found at Harappa appear to be coming from these regions. The numerous large deposits of massive "snow white gypsum" that are found across that state are thought to be of Precambrian age (Krishnaswamy 1979: 251-252; Mehta 1957: 61-62; Singh *et al.* 1994). Harappans interacting with Neolithic peoples in the Kashmir Valley (Saar 1992) via the upper Jhelum River valley would have had access to both lead and alabaster in the vicinity of Buniyar (Middlemiss 1929: 3). Similarly, the residents of the Harappan site of Manda (Joshi and Bala 1982) would have been well positioned to exploit the alabaster (Sinha 1967: 298) and lead deposits of Jammu.

#### *Western Himalayas*

Southwest of Jammu and Kashmir (not pictured on Figure 10.5) sporadic occurrences of alabaster can

be found in the Carboniferous era formations of the western Himalayas (Wadia 1975: 467). In the Kinnaur District of Himachal Pradesh, alabaster occurs in the Lipak Formation (Geological Survey of India 1989a: 29). In the Garhwal region of Uttaranchal, deposits are found in the Krol Formation (Chatterjee 1963b: 227). Although no Harappan sites lie within the Himalayas, some have been discovered in the foothills of that range near Chandigarh (IAR 1985-86: 15) and around Ropar (Sharma 1982).

## DETERMINING THE GEOLOGIC PROVENIENCE OF HARAPPAN ALABASTER ARTIFACTS

N.H. Gale and others (1988) successfully employed both sulfur isotope analysis and strontium isotope analysis to characterize gypsum deposits in Greece and to assign a geologic provenience to alabaster artifacts from several Mycenaean sites. The same combination of techniques are used in this study to analyze a group of Harappan alabaster artifacts and compare them to a set of geologic materials from potential sources in Pakistan. To begin this section, I provide the geologic background pertaining to alabaster-bearing marine evaporites, relate how the changing isotopic characteristics of seawater makes studies of this kind possible and discuss what might be expected when samples in sets assembled for this study are analyzed. I then present the results of the isotopic analyses and provenience determinations suggested by them – this is done first for each isotopic system alone and then in combination with one another. In the concluding part of this section I discuss diachronic and synchronic patterns of alabaster source usage at Harappa that are evident based on the results of these studies.

### Geologic background – marine evaporites and isotope curves for S and Sr in seawater

The massive beds of alabaster found in the Salt Range, Sulaimans and Kohat are believed to be marine evaporites (Alam and Khan 1982: 3; Bender 1995b: 264). Deposits of this kind form as gypsum precipitates from seawater evaporating in shallow, semi-restricted marine basins (Blatt 1992: 348-350). The alabaster beds of Eocene age that are being considered here would have been originally laid down in the ancient Tethys Sea as it gradually closed between the Indian Subcontinent and the Eurasian Plate beginning around 55 million years ago (Powell 1979: 16). The Infra-Cambrian deposits are perhaps remnants of a similar, but much earlier, process.

The very different ages of the geologic formations under examination here actually facilitates the effort to determine the geologic provenience of alabaster artifacts from Harappa and other Indus Civilization sites. The reason is that the isotopic compositions of certain elements in the waters of the earth's oceans have undergone considerable changes over time. Sedimentary rocks of marine origin (evaporites like alabaster and carbonates like limestone) contain a record of the sulfur and/or strontium isotope characteristics of seawater during the period of time that they formed (Faure and Mensing 2005: 440-441, 833-835). Analysis of marine evaporites and carbonates of different ages from around the world have enabled geologists to construct isotope "curves" that plot the diachronic changes in the compositions of those elements in seawater. Alabaster artifacts can, with reference to either or both isotope curves, be matched to a geologic formation having analogous isotopic characteristics.

In the two sub-sections to follow, I provide short explanations of the sulfur and strontium isotope curves and an outline of how the alabaster source formations under examination here might expected to plot in relation to them.

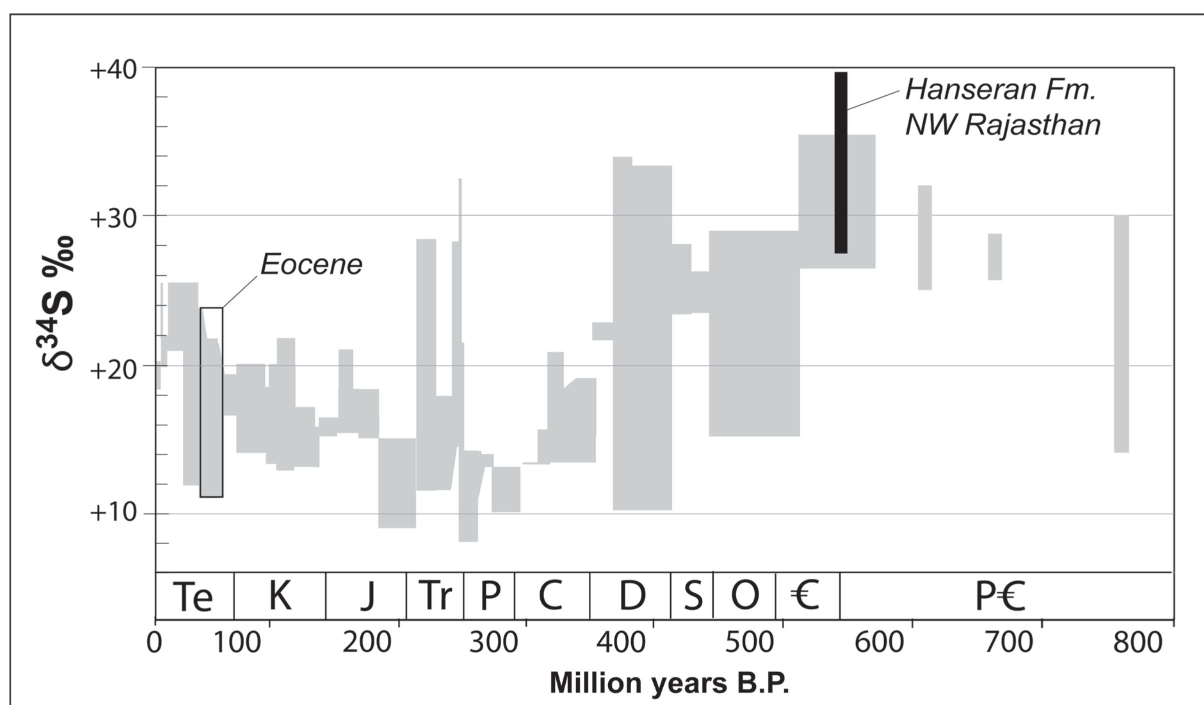



**Figure 10.12** Variation in the isotopic composition of sulfur in seawater through time (after Shields *et al*. 2004 and Strauss 1997).

*The sulfur curve*

The element sulfur (S) has four stable isotopes ($^{32}S$, $^{33}S$, $^{34}S$, $^{36}S$). The ratio of the two most abundant of these ($^{32}S$ and $^{34}S$) in a sample is measured with a mass spectrometer. The results are expressed using the notation $\delta^{34}S$ ‰, which represents the per mil (‰) deviation in the $^{34}S/^{32}S$ ratio measured in the sample compared to that measured in the Canyon Diablo Troilite (CDT) meteorite international standard (Eckhardt 2001: 514). Since sulfur isotopes do not undergo substantial fractionation as gypsum is precipitated, the isotopic composition of that element in an alabaster deposit should be essentially the same as the ancient seawater from which it derived (Faure and Mensing 2005: 833).

The isotopic composition of sulfur in seawater has changed through time and a record of this has gradually been generated through the analysis of marine evaporite sulfate deposits of different ages from around the world (Straus 1997). A representation (the sulfur isotope "curve") of these changes over geologic time can be seen in Figure 10.12. Prior to this study no sulfur isotope analysis had ever been performed on marine evaporites from the three geologic formations under examination here. Nevertheless, based on the sulfur isotope curve we would expect that the Eocene alabaster deposits (and artifacts deriving from them) would have $\delta^{34}S$ ‰ values ranging from approximately +11 to +24 (range noted on Figure 10.12). As for the deposits of Infra-Cambrian age, Harald Strauss and others (2001) analyzed 26 marine sulfate samples from the Hanseran Formation of northern Rajasthan, which is generally considered to be analogous to the Salt Range Formation of the Punjab. This formation was not discussed above because it is located at a minimum at a depth of nearly 300 meters below the surface (Strauss *et al*.'s samples came from drill cores) and therefore could not have been a source of Harappan alabaster. However, Hanseran marine sulfates have $\delta^{34}S$ ‰ values ranging from +27.5 to +39.7 (range noted on Figure 10.12) and so similar values might be expected from Infra-Cambrian Salt Range Formation alabaster deposits and artifacts deriving from them.

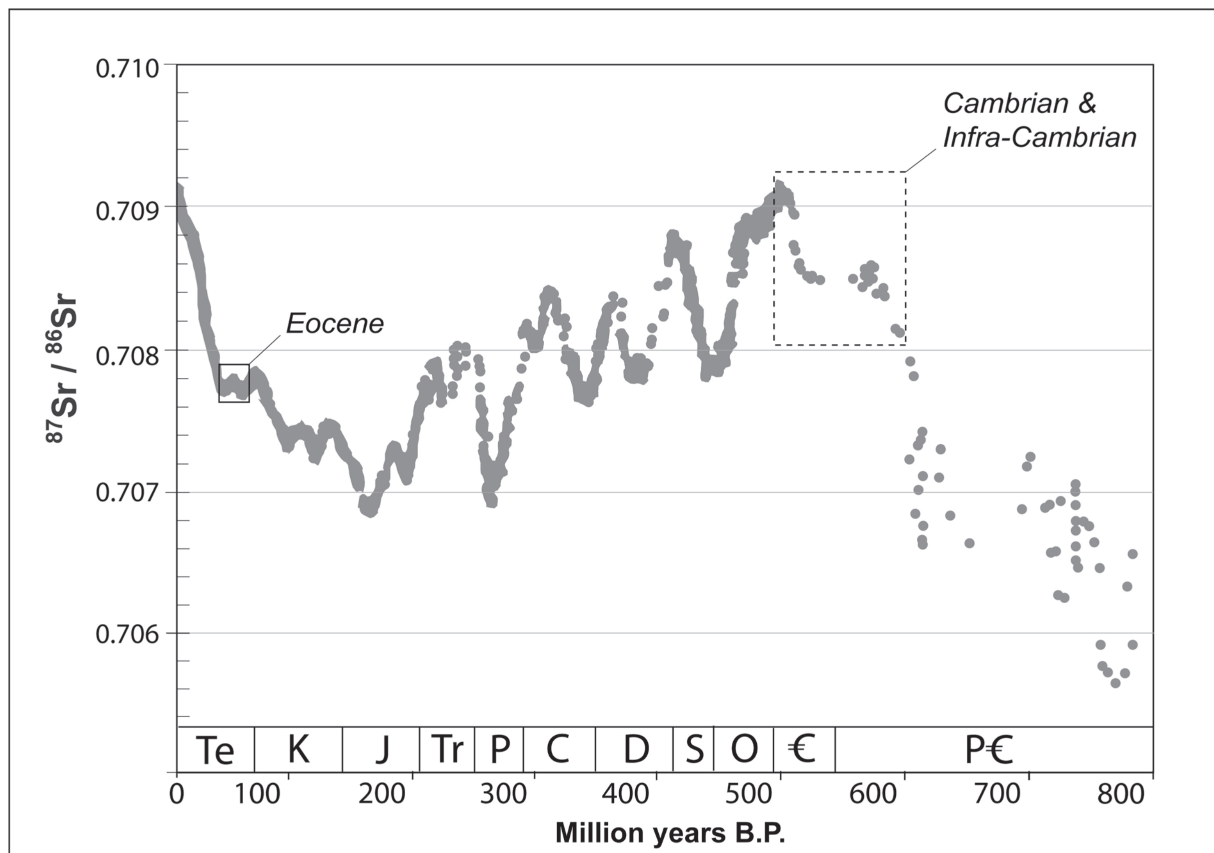



**Figure 10.13** Variation in the isotopic composition of strontium in seawater through time (after McArthur *et al*. 2001).

*The strontium curve*

The element strontium (Sr) also has four stable isotopes ($^{84}$Sr, $^{86}$Sr, $^{87}$Sr, $^{88}$Sr). In geologic materials $^{87}$Sr is augmented over time by the decay of a radioactive isotope of rubidium – $^{87}$Rb (Faure and Mensing 2005: 75). However, because the amount of $^{87}$Rb in gypsum is extremely low and therefore very little radiogenic $^{87}$Sr is generated over time, the overall Sr isotope composition of an alabaster deposit will essentially be the same (barring any later digenetic changes) as the seawater from which it precipitated (Gale *et al*. 1988: 59-60). A mass spectrometer is used to measure the ratio of all the strontium isotopes. The ratio of $^{86}$Sr/$^{88}$Sr, which is constant on the earth, is used to correct the $^{86}$Sr/$^{87}$Sr ratio for instrumental mass bias resulting in the very precise determination of the $^{87}$Sr/$^{86}$Sr ratio (Dr. Joel Blum, *personal communication* 2005).

Like sulfur, the isotopic composition of strontium in seawater has changed through time. A record of the changes has been generated through the analysis of marine carbonates (fossil shells and limestones) of different ages from around the world (Veizer *et al*. 1999). A curve depicting the changing strontium isotope characteristics of seawater through the Phanerozoic (Cambrian Period to present) can be seen in Figure 10.13. Although none of the formations being investigated in this study were previously analyzed, the strontium isotope composition of those marine sulfates should be analogous to carbonates formed during the same periods of time. With reference then to the strontium curve published by McArthur and others (2001), the Eocene period alabaster deposits and artifacts deriving from them would be expected to have $^{87}$Sr/$^{86}$Sr ratios ranging from approximately 0.7076 to 0.7079 (noted on Figure 10.13). The Sr isotope composition of the oceans prior to the Cambrian Period is not well constrained due to the fact that carbonate rocks from that time are scarce and those that do exist have often

been altered (Faure and Mensing 2005: 447-448). Geologic samples and artifacts from Infra-Cambrian deposits could have $^{87}Sr/^{86}Sr$ values similar to those of the Cambrian Period – from approximately 0.7080 to 0.7093 (ibid.: Figure 19.6). It is also possible that those deposits might have even higher values. Precambrian marine carbonates in the western Himalayas often have highly radiogenic Sr isotope compositions (from approximately 0.7090 to 0.7323 or even higher) due to isotopic exchange with high $^{87}Sr/^{86}Sr$ silicate rocks during metamorphism (Blum *et al*. 1998; Jacobson *et al*. 2002; Sarkar *et al*. 1996; Singh *et al*. 1998). Precambrian/Infra-Cambrian evaporate deposits of that region may well have been affected in the same way.

### Sulfur and strontium isotope analyses of geologic sources and Harappan artifacts

Two sets of alabaster samples were prepared for sulfur and strontium isotope analysis – a set of archaeological samples and a set of geologic source materials. Details regarding the 33 artifacts comprising the archaeological set (Appendix 10.1) were presented in preceding sections. Twenty-nine samples came from Harappa, two from Musa Khel and one each from Rehman Dheri and Mohenjo-daro. Both sulfur and strontium isotope analysis are destructive methods and so some material needed to be removed from each artifact. For this reason two-thirds of the samples were chosen because they were unworked, non-diagnostic alabaster debris fragments. Samples that came from finished objects were taken from an already broken or cracked area. Using a fine tungsten carbide drill the weathered surface of an artifact was burred away from a small circular area approximately 2 mm in diameter. The surface material was discarded and then drilling of the freshly exposed area continued until approximately 50 mg of powder was generated. The powder was then divided and placed into two small polyethylene vials for transport to the laboratory. The full set of 33 artifacts was analyzed for sulfur isotope composition but it was only possible to make Sr isotope determinations on 30 of them.

The geologic set consisted of 46 samples – 24 samples from 12 individual deposits in the Sulaiman Mountains, four from two deposits in Kohat and 18 samples from seven deposits in the Salt Range (Appendix 10.2). All of the sampled locations are identified on Figure 10.5. Approximately 200 mg of material was removed from an unweathered, freshly broken surface on each geologic sample and powdered in an agate mortar. The powder was then divided and placed into two small polyethylene vials for transport to the laboratory. The full set of 46 geologic samples was analyzed for sulfur isotope composition but it was only possible to make Sr isotope determinations on 39 of them.

#### *Sulfur isotope analysis and results*

Sulfur isotope analysis of the sample sets was conducted by Dr. Chris Eastoe at the Isotope Geochemistry Laboratory, University of Arizona. Each sample was dissolved in HCl and then a $BaCl_2$ solution was added to precipitate $BaSO_4$, which as then filtered and dried (Isotope Geochemistry Laboratory 2004). Sulfur dioxide gas was extracted from the $BaSO_4$ by combustion with $V_2O_5$ (Yanagisawa and Sakai 1983) in a Costech elemental analyzer. From that gas $\delta^{34}S$ values were measured a Finnigan Delta PlusXL continuous-flow gas-ratio mass spectrometer. International sulfur standards OGS-1 and NBS123 were used along with several other sulfide and sulfate materials that have been compared between laboratories. Based on repeated use of internal standards the precision was estimated to be ± 0.15 or better (Chris Eastoe personal communication 2004).

The sulfur isotope analysis results for the geologic and archaeological sets are listed in appendices 10.1 and 10.2 and are plotted on Figure 10.14. Samples in the geologic set largely fall where predicted by the

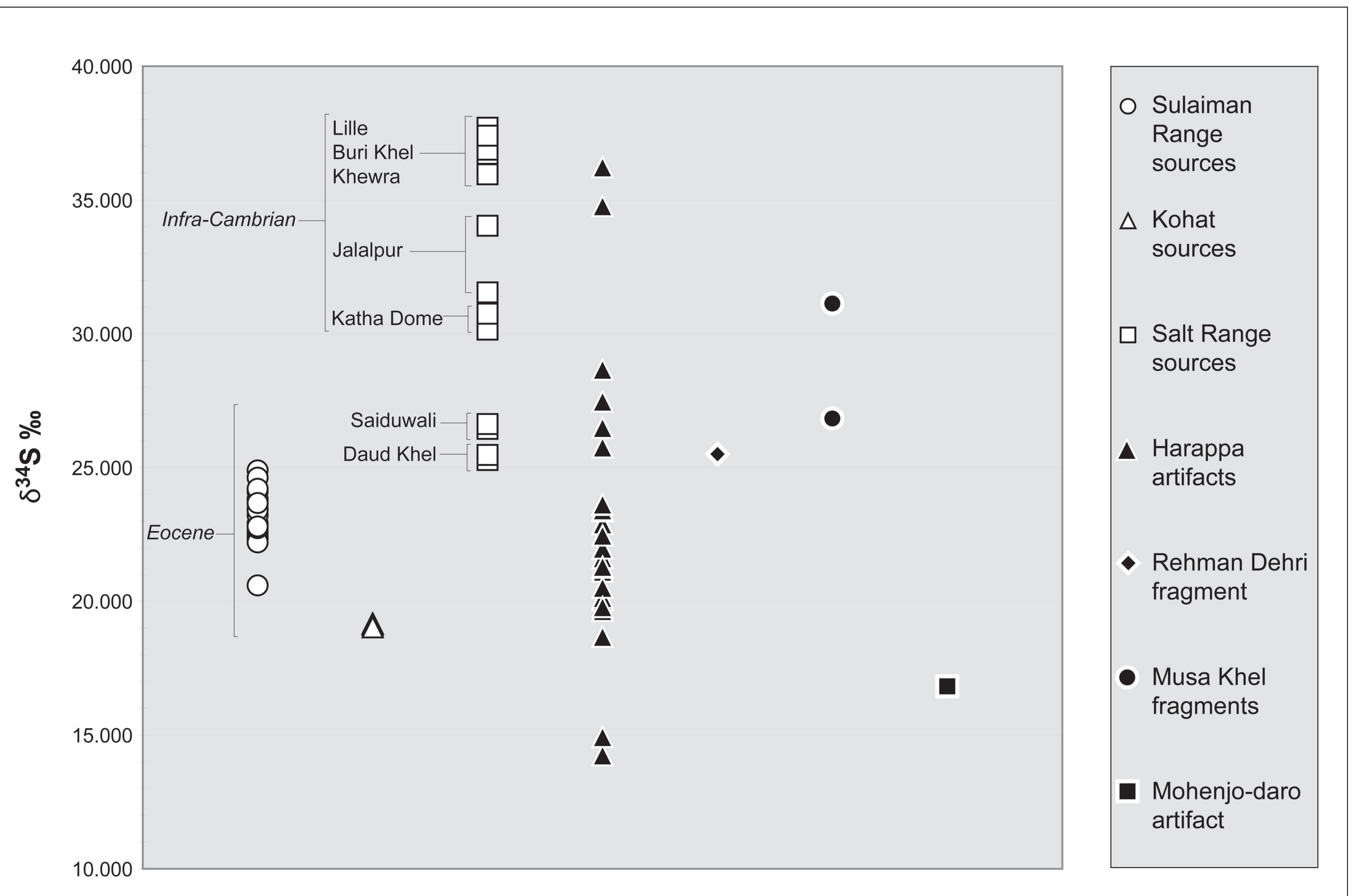



**Figure 10.14** Sulfur isotope values for alabaster sources in Pakistan and artifacts from Harappa and three other sites.

sulfur isotope curve for Phanerozoic seawater. The Infra-Cambrian deposits of the Salt Range Formation (noted on the figure) have $\delta^{34}S$ values from +30.15 to +30.69, which is typical of other deposits of that age and places them within the range measured by Strauss and others (2001) for the Hanseran Formation of northern Rajasthan. Most of the Eocene alabaster sources of the Sulaiman Range and Kohat had $\delta^{34}S$ values ranging from +19.02 to +24.89, which would be expected of deposits of that age. The exceptions were the two Eocene deposits of the western part of the Salt Range (Saiduwali and Daud Khel – also noted on the figure), which had slightly higher than expected values (from +25.27 to +26.62).

When archaeological samples are plotted in relation to the geologic sources it appears that alabaster artifacts from Harappa derive from all three regions examined here and as well as, possibly, a fourth unknown source. It seems clear that the two artifacts with the highest $\delta^{34}S$ values came from Infra-Cambrian sources in the eastern part of the Salt Range. Four others are much more closely related sources in the western Salt Range. The two artifacts with $\delta^{34}S$ values below +15.00 would appear to come from an alabaster source other than the three examined here. The bulk of the alabaster artifacts from Harappa, however, have $\delta^{34}S$ values that span the range of variation seen for deposits within the Sulaiman Range and between that region and the Kohat sources. Although some are clearly more analogous to Sulaiman sources than to those in Kohat and vice versa, several plot in an area (approximately +20.00) that falls ambiguously between the two regions.

The artifacts from the other Indus sites plot in both expected and interesting ways. The $\delta^{34}S$ value for the Rehman Dheri fragment not surprisingly falls within the range of the sources closest to that site in the western Salt Range. Although the two fragments analyzed from Musa Khel also plot with Salt Range sources, they appear to probably be from two different deposits. One has a $\delta^{34}S$ ratio value that would indicate that it came from an Eocene source in the western part of the range while the other may have derived from an Infra-Cambrian source farther east. The single sample from Mohenjo-daro does not appear to have come from any of the three regions examined here but may have derived from the same unknown source as the two Harappan samples with the lowest $\delta^{34}S$ values.

***Strontium isotope analysis and results***

Strontium isotope analysis of the sample sets was conducted by Joel Blum and Andrea Klaue at the Department of Geosciences, University of Michigan–Ann Arbor. Samples were dissolved and strontium was separated from them by cation exchange chromatography following the procedures outlined by Blum and others (1998). $^{87}Sr/^{86}Sr$ ratios were measured on a Finnigan MAT 262 thermal-ionization mass spectrometer (TIMS) and normalized to $^{86}Sr/^{87}Sr$ = 0.1194. Replicate analysis of the NIST SRM-987 standard yielded a value of 0.710250 ±0.000014 ($2\sigma$, n= 74). The precision of individual analyses was at least ±0.000 020 ($2\sigma$).

The results of strontium isotope analysis of the geologic and archaeological sets are listed in appendices 10.1 and 10.2 and are plotted on Figure 10.15. The various geologic sources examined had $^{87}Sr/^{86}Sr$ values that were, for the most part, within the ranges expected for deposits of those ages with regard to the strontium isotope curve. The Infra-Cambrian alabaster deposits of the Salt Range Formation had ratios from 0.708048 to 709053 – a range comparable to those for late Precambrian to Cambrian formations found elsewhere (highlighted and labeled on Figure 10.13). A single sample of this age from the Jalalpur area had the somewhat high value of 0.710204. Ratios for alabaster occurrences in the Sulaiman Range clustered from 0.707704 to 0.707846 – exactly within the fairly restricted range expected for Eocene marine evaporites (highlighted and labeled on Figure 10.13).

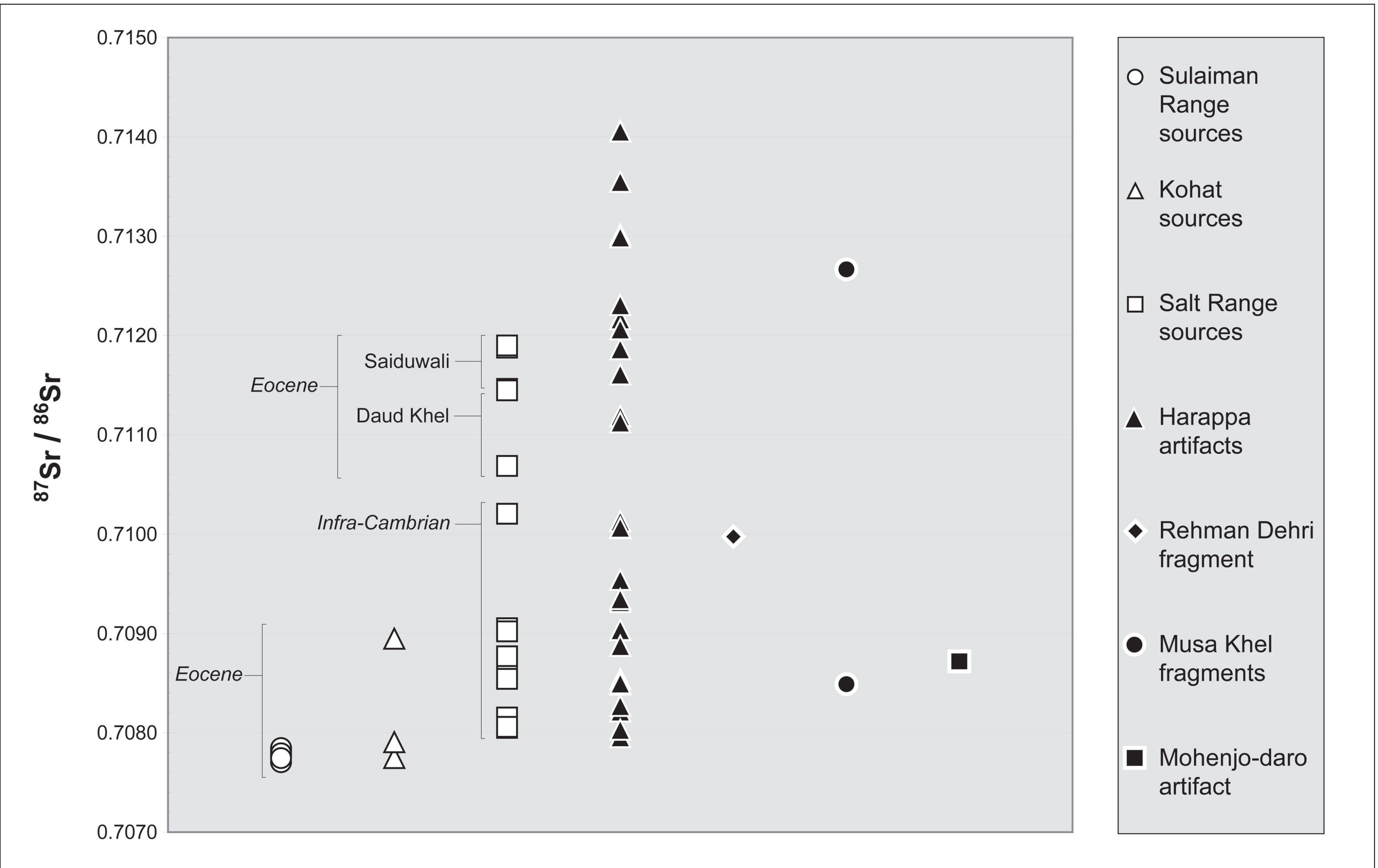



**Figure 10.15** Strontium isotope values for alabaster sources in Pakistan and artifacts from Harappa and three other sites.

Eocene deposits in Kohat also plot where predicted with the exception of a single sample from the Jatta deposit that has the slightly higher ratio of 0.708949.

When the alabaster sources of the western Salt Range, Saiduwali and Daud Khel (identified with brackets on Figure 10.15), are compared to the strontium isotope curve it becomes evident that they have unusually high $^{87}Sr/^{86}Sr$ ratios (from 0.710686 to 0.711899), especially for deposits of Eocene age but also for typical marine evaporite of Cambrian/Infra-Cambrian age. These same two deposits likewise had higher than expected sulfur isotope values. It was noted above there are some formations of sedimentary marine rocks in the western Himalayas that, having been metamorphosed together with high $^{87}Sr/^{86}Sr$ silicate rocks, are enriched with highly radiogenic strontium. The alabaster deposits of the western Salt Range do not appear to have been metamorphosed, however. Whatever the cause(s) for their unusually high isotopic values is eventually determined to be, the Eocene alabaster sources of the western Salt Range are quite clearly distinct from both the Infra-Cambrian deposits to their east and those of the same age in the Sulaiman Range and Kohat.

When the strontium isotope ratios of archaeological samples are plotted in relation to the geologic sources the pattern that emerges is very different and seemingly contradictory to the one suggested by the sulfur isotope results. Whereas only six of the 29 samples from Harappa were assigned to Salt Range alabaster sources based on sulfur isotope analysis, 26 samples in the set now fall within or very near the range of variation for Salt Range deposits. The three samples plot higher than any of the geologic sources analyzed here. Due to the single Kohat sample with a high $^{87}Sr/^{86}Sr$ ratio, seven of the archaeological samples are also encompassed within the range of variation for that source region. No samples plot within the very tight strontium isotope range for Eocene deposits in the Sulaiman Range whereas 14 artifacts did when sulfur isotopes were examined.

Artifacts from the other Indus period sites plot in somewhat different ways as well. Although the Rehman Dheri fragment would still be assigned a Salt Range provenience based on its $^{87}Sr/^{86}Sr$ ratio, it now appears more analogous to Infra-Cambrian deposits in the eastern part of that range rather than to the nearest source at Saiduwali. The fragments analyzed from Musa Khel again appear probably to be from two different sources – one from an Infra-Cambrian deposit and one, perhaps, from the Eocene sources (although it has a ratio that is somewhat higher than those measured from Saiduwali or Daud Khel). The vessel fragment from Mohenjo-daro now falls within the range of both Infra-Cambrian deposits of the Salt Range and the Eocene Deposits of Kohat whereas based on sulfur isotopes it seemed to have been unrelated to any of the three geologic sources.

A handful of archaeological samples have $^{87}Sr/^{86}Sr$ ratios that are higher (in some cases significantly higher) than any of the geologic sources analyzed here. The possibility exists that alabaster artifacts may have been post-depositionally altered in a way that affected the isotopic composition of strontium within them. The waters of the rivers draining the Himalayas are known to have elevated levels of radiogenic strontium due to factors relating to the types of rocks eroding in their upper courses (Singh *et al.* 1998; Sarkar *et al.* 1996). A water sample taken from the Ravi River upstream from Harappa had a $^{87}Sr/^{86}Sr$ ratio of 0.729120 (Karim and Veizer 2000). Since the introduction of widespread canal irrigation in the late 19th century and early 20th century the water table has risen significantly in this part of the Punjab as well as farther south in Sindh (Michel 1972). Soil salinity had become tremendous problem in these areas and archaeological sites like Harappa and Mohenjo-daro have suffered considerably as moisture moves to the surface through the mounds and artifacts it contains. Porous materials have become impregnated with salt and, presumably, other dissolved elements in the

water. As for alabaster artifacts, great care was taken to get below their weathered surfaces and collect material for analysis from the (hopefully) unaltered interiors. The high $^{87}Sr/^{86}Sr$ ratios exhibited by certain samples may very well be a characteristic of the geologic source(s) – possibly in the western Himalayas (Jammu and Kashmir), they derive from. However, until sources there are analyzed the possibility that alabaster artifacts may have been contaminated by radiogenic strontium from the rivers of the Punjab must be recognized.

***Bivariate plotting of the S and Sr analysis data***

The seemingly contradictory provenience determinations derived from the sulfur and strontium isotope data might lead one to surmise that either one or both of the methods used were flawed, either in their execution or premise. This is almost certainly not the case, however, as demonstrated by the data resulting from the analyses of the geologic sample set. The isotopic behavior of Phanerozoic seawater is well understood and the assays made here of samples from deposits of marine evaporites of known ages provided values that were, in the great majority of instances, spot on with regard to the expected isotopic compositions predicted by both the sulfur and strontium curves. Exceptions were probably due to as yet not well understood characteristics of particular geologic formations. Any apparent incongruities between how the archaeological set plotted in relation to the isotope curves are no doubt the result of the geochemical properties of the artifacts themselves. It is important bear in mind that each element alone provides only one dimension with which to examine the possible provenience of archaeological alabaster. Considering sulfur and strontium data simultaneously allows a fuller picture of the isotopic variability (or similarity) between geologic formations and artifacts to be generated.

Figure 10.16 is a bivariate plot of the sulfur and strontium isotope data for samples from the geologic and archaeological sets. Strontium values are found on the y-axis and sulfur values on the x-axis. In this new two-dimensional view the three main geologic source regions are even more isotopically distinct from one another than before. The geographically widespread Eocene alabaster deposits of the Sulaiman Range still cluster in a tight a pattern and appear most closely related to sources of the same age in Kohat. Lying in contrast to those deposits and to one another are the two different formations of the Salt Range (circled on Figure 10.16). The high strontium isotope values for Salt Range Eocene alabaster deposits set these clearly apart from all other formations.

The archaeological samples are plotted on Figure 10.16 as black shapes. From this it is evident that at least some of the artifacts from Harappa (triangles) are isotopically analogous, or at least very similar, to the geologic formations examined here. Several fall directly upon or plot within the area encompassed by the geologic sample data points of both the Eocene (Sakesar) and Infra-Cambrian (Salt Range) formations in the Salt Range. Others cluster on and near data points for the Eocene sources in the Sulaiman Range and the Kohat region. Over half of the Harappan samples, however, plot in areas away from these geologic formations. Of those that do, many have high $^{87}Sr/^{86}Sr$ ratios like the Salt Range Sakesar deposits but with slightly lower $\delta^{34}S$ values that cause them to fall in a loose cluster above and to the left of that formation. It is difficult to say if these seemingly similar archaeological fragments actually represent a single source formation or multiple ones. If we use the Infra-Cambrian formation of the Salt Range as a model then it is evident that individual deposits of a single formation can spread widely. Conversely, the isotopic ranges of the geographically widespread Eocene sources of the Sulaimans and Kohat are much more constrained. It is important to point out that only five data points presently exist for the Sakesar Formation deposits, which lie adjacent to this cluster. The possibility exists that future analyses

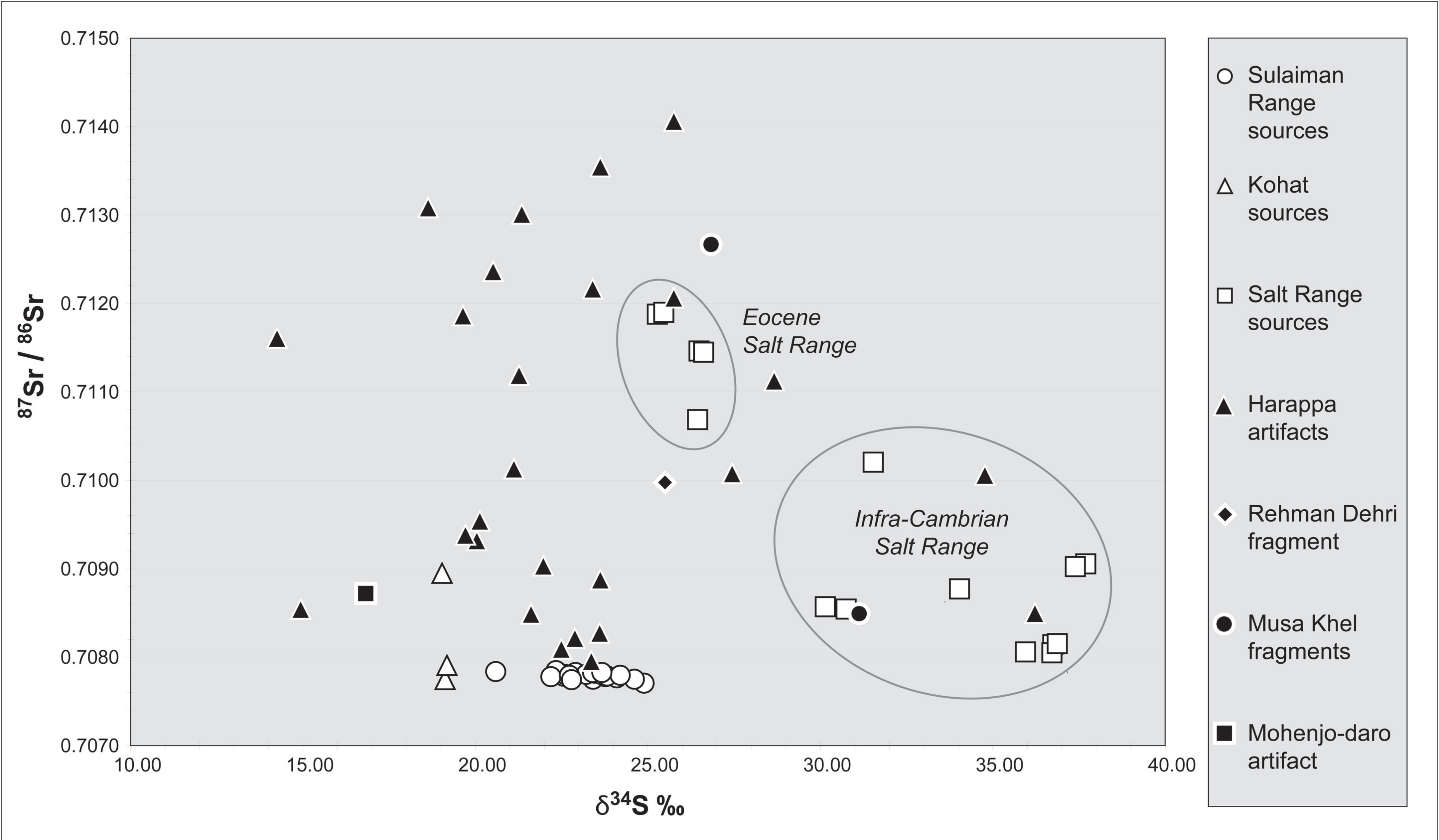



**Figure 10.16** Bivariate plot of strontium and sulfur isotope values for alabaster sources in Pakistan and artifacts from Harappa and three other sites.




**Figure 10.17** Labeled bivariate plot of strontium and sulfur isotope values for alabaster sources in Pakistan and artifacts from Harappa and three other sites.

of geologic source material (from the same deposits and additional ones) might eventually enlarge the isotopic boundaries the Sakesar marine evaporates to encompass some of those ungrouped artifacts. On the other hand, it is also very possible that the raw material for those artifacts may have come from one of the potential sources discussed above that has not yet been analyzed. The most obvious candidates would be those alabaster deposits in parts of the western Himalayas where marine carbonates are known to have similarly high levels of radiogenic strontium.

The way in which the alabaster samples from the other prehistoric sites fall on the bivariate plot is informative. Once again the two fragments from the site of Musa Khel (black circles) appear to be from different Salt Range formations – one clearly comes from an Infra-Cambrian deposit and the other falls quite close to the Eocene age sources. The latter fragment, along with the one from Rehman Dheri (black diamond), provide a good indication of how the isotopic boundaries of Salt Range Eocene alabaster deposits might expand when additional analyses are undertaken of geologic samples from the Sakesar Formation. The alabaster vessel fragment from Mohenjo-daro (black square) along with a single fragment from Harappa stand apart due to their low sulfur and strontium isotope values. Although these two samples could be from a deposit related to the Eocene source formations of the Sulaiman Range or Kohat, they are clearly not from the Salt Range. Certain trade items such as chlorite vessels were brought to Indus cities like Mohenjo-daro from regions far beyond the Indus Valley (Kohl 1975, 1979). It is therefore possible that these alabaster artifacts, and perhaps some others, originated from sources much more distant than the ones discussed in this chapter.

## Chronological and spatial interpretation of alabaster provenience determinations

It has been demonstrated that at least some of the alabaster artifacts from Harappa probably came from the geologic sources analyzed for this study. The provenience of other artifacts remains unclear. Nevertheless, much can still be learned about acquisition and use of alabaster at Harappa by examining the patterns derived from the isotopic data in tandem with the temporal and spatial contexts of the archaeological samples.

Figure 10.17 is a version of the bivariate plot of sulfur and strontium isotope data that has been modified to help illustrate some of the points that I discuss in this sub-section. On it, the individual deposits in the Salt Range are noted and archaeological samples from Harappa are labeled with a three part code that denotes artifact type (the type key is on the figure), period and mound of origin. For example, an artifact coded "F-3C(AB)" is an alabaster fragment recovered from Period 3C levels on Mound AB. The dashed ellipses that have been added to the figure represent the possible extent (isotopic boundaries) of geologic sources. These are admittedly speculative and do not represent statically generated confidence intervals. The Infra-Cambrian source area was the only one that was demarcated based on geologic samples alone. The dashed ellipse marking the Eocene Salt Range deposits was drawn to encompass archaeological samples from the sites of Rehman Dheri and Musa Khel, which presumably come from that formation. The Sulaiman-Kohat ellipse is based partly on geologic samples from those regions and partly on archaeological samples that cluster on or nearby them. A final ellipse was drawn to encompass the loose cluster of archaeological samples that plot above and to the left of the Salt Range Eocene deposits.

With reference to Figure 10.17, I begin by examining alabaster source utilization through time. To date only six alabaster artifacts have been recovered from levels earlier than Period 3 at Harappa – three from Period 1 and three from Period 2. Of these, two fragments from Period 2 were analyzed for

this study and both appear to have come from Salt Range sources – one from an Eocene deposit and the other from an Infra-Cambrian deposit. Albeit the sample size is very small, the utilization of alabaster from sources north of Harappa is very much in line with the acquisition patterns being observed for other rock and mineral resources during the Early Harappan Period such as grindingstone (Chapter 5), chert (Chapter 6), steatite (Chapter 7) and lead (upcoming - Chapter 12). Note on the figure that there are also alabaster fragments from Period 3C with isotopic values analogous to deposits in the Salt Range. This provides further evidence (along with steatite, vesuvianite-grossular and lead) that Harappans continued to utilize materials from this northern zone well into the urban phase.

Evidence has been presented throughout this book that indicates the emergence of fully urban lifeways at Harappa coincided with an increase in both the number of rock and mineral varieties being brought to the site and the overall number of source regions around the Greater Indus from which such materials were being obtained. This trend towards diversification is yet again apparent with regard to the alabaster acquisition networks in which Harappans were involved during Period 3. Although only a few artifacts coming from periods 3A (n=1) and 3B (n=2) have been analyzed, most of them have isotopic characteristics that clearly set them apart from Salt Range deposits, which suggests that new sources had come into use. Sulfur and strontium isotope data exists for 16 alabaster artifacts from Period 3C levels. It appears from the way these artifacts plot on the figure that, in addition to the two different formations of the Salt Range (discussed above), raw material from at least two other sources (and possibly several more) was being brought to Harappa at this time. One of these new source regions appears to have been the Eocene deposits to the west and northwest of Harappa. Although I have demarcated this cluster with a single ellipse, some of the artifacts in it closely group with Sulaiman Range deposits while others appear more like Kohat material. It is highly probable that the smaller clusters of artifacts within the ellipse represent materials from multiple deposits across these geologically related regions. Another apparent source (or sources) is represented by the widely spaced cluster of artifacts with high $^{87}Sr/^{86}Sr$ ratios labeled "unknown." This is the group that may or may not be related to the Eocene formation of the Salt Range. There are also scattered cases where artifacts seemingly plot away from or between the main clusters. These may represent materials from still other sources or they may just be outliers of either the known or proposed geologic formations. Despite the fact that the geologic provenience of these and many other archaeological samples remains unclear, it is certainly well evident that during Period 3C Harappans were utilizing alabaster from at least three or four different source regions.

Lastly, we turn to synchronic variation of alabaster source usage at Harappa. It was stated toward the beginning of this chapter that, aside from the fact that residents of Mound E were apparently the only ones creating and/or consuming alabaster bangles, there does not appear to have been a great deal of intra-site variation in terms of the utilization of this material during Period 3C. Interesting patterns that seem to suggest otherwise, however, become evident when artifacts from this period are examined in relation to their possible geologic provenience. It would appear that the only Harappans using alabaster from the "unknown" source formation were those living and working on mounds E and ET. Residents of those areas also obtained some of that material from most other available sources with the exception of the Salt Range Infra-Cambrian deposits. People on Mound AB at this time utilized material from both Salt Range formations as well as the Sulaiman-Kohat sources. The Harappans of Mound F appear to have gotten their alabaster exclusively from deposits located in the Sulaiman Range.

Although these results seem to suggest that there might have been genuine differences in alabaster acquisition between peoples dwelling/working in the various habitation at Harappa, caution is advised because of the very small samples sizes involved in this study (only two to five artifacts from each of the major mounds have been analyzed for this period). Many more analyses of artifacts from the different parts of the site will eventually need to be conducted in order to determine if these patterns are valid.

## CHARACTERIZATION OF MARI "DIAMONDS" FROM HARAPPA

A number of small (≈ 1 cm) pink-colored quartz crystals have been recovered at Harappa that could potentially provide an added dimension to this study of Harappan alabaster acquisition networks. If not for the highly distinctive bi-pyramidal shape of these artifacts (three examples can be seen in Figure 10.18 A) they would have simply been recorded as examples of common rose quartz. However, crystals of this exact description are known to occur within massive gypsum (Figure 10.18 B) found at certain locations in the Salt Range. The best known occurrences are located on either side of the Indus River at the point where it passes through the Salt Range and onto the Punjab Plain (Punjab Government 1907: 203). Local residents have long been known to search through the gypsum and salt marls of "Diamond Hill" near the village of Mari Indus (Figure 10.18 C) for these unusually shaped quartz crystals, or Mari "Diamonds," which they fashioned into necklaces (Alam and Khan 1982: 8; Wynne 1878: 300). In the site report for Mohenjo-daro, Sir Edwin Pascoe specifically mentions this source in the section outlining possible sources of rock crystal (Pascoe 1931: 678). It is unclear, however, if any quartz artifacts having this unusual shape were ever encountered at Mohenjo-daro or if the pink bi-pyramidal quartz crystals found at Harappa actually came from the Salt Range. Dr. Albert Verchere (cited in Government of the Punjab 1883-84: 18) noted bi-pyramidal quartz crystals in the brecciated gypsum of the Waziristan Hills. In the stone bazaar of Peshawar, I examined examples of similar crystals embedded in a gypsum matrix that were attributed to Afghanistan's Paktia Province, which lies adjacent to Waziristan. Bi-pyramidal crystals called "diamond quartz" are also known from the Karnur area of Tamil Nadu in southern India (Karnath 2000: 251, Figure 10.7a). The nearest occurrences to Harappa, however, are those in the Salt Range. If it could be shown that the Harappan examples are indeed Mari "Diamonds," then that would be an excellent second line of evidence indicating the exploitation of alabaster deposits in that region during the prehistoric period.

In addition to their unusual shape, petrographic studies (Chhibber 1944; Lenk-Chevitch 1955; Holland 1891) have revealed that Mari "Diamonds" from the Salt Range contain minute inclusions of anhydrite – calcium sulfate ($CaSO_4$) – which is basically gypsum without the water component. It is highly unusual to find this mineral within the structure of a crystal and can certainly be taken as indicative of its formation within a gypsum, alabaster or anhydrite deposit. No quartz crystals, bi-pyramidal or otherwise, have ever been reported to occur in either the Balochistan or Kohat alabaster deposits and, as far as I have been able to determine, quartz crystals (of any shape) containing inclusions of anhydrite inclusions do not occur in other geologic environments in South Asia.

In order to determine if the small pink-colored bi-pyramidal quartz crystals from Harappa are indeed Mari "Diamonds," two examples were selected for characterization using electron microprobe analysis (refer to the section on EMPA in Chapter 3 for details regarding this technique). Back-scattered electron imaging (Figure 10.18 D & E) revealed that both of the crystals examined were filled with inclusions ranging from approximately 20 to 200 µm

**Figure 10.18** Mari "Diamonds" – artifacts, sources and analyses



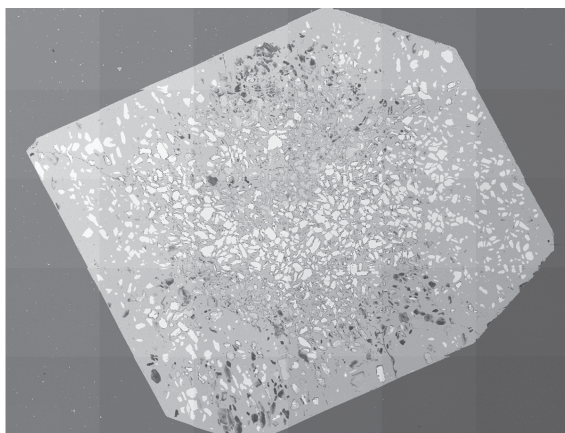

**A.** Three examples of unusual pink-colored bi-pyramidal quartz crystals recovered at Harappa.



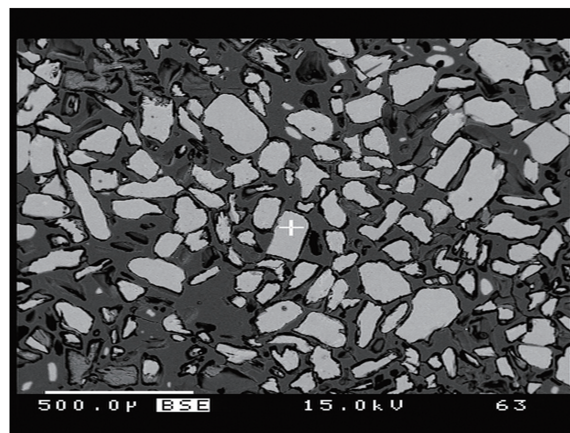
**B.** Quartz crystals in gypsum-anhydrite matrix from Mari Indus.



**C.** Gypsum and salt marls at Mari Indus, District Mianwali, Punjab, Pakistan



**D.** Back scatter electron image of a section of an inclusion-filled Mari "Diamond" from Harappa.




**E.** Detail of anhydrite inclusions in Mari "Diamond."

(microns) in size. Scans with the microprobe's energy dispersive spectrometer (EDS) indicated that these inclusions were indeed composed of anhydrite. These results strongly support the conclusion that crystals at Harappa with this unique visual appearance are indeed Mari "Diamonds" from the central Salt Range.

To date, ten Mari "Diamonds" have been recovered at Harappa (Appendix 10.3) and none of them appear to have been intentionally modified in any way. It is possible that these examples were transported to the site within the matrix of a piece of raw alabaster and subsequently discarded. Small pieces of pink colored quartz are occasionally found that may represent examples that broke as craftsmen attempted to work them. However, most of these pieces are too fragmentary to determination if they were bi-pyramidal like Mari "Diamonds" and so have not been given that classification until such time as they can be characterized in greater detail using EMPA.

Although few artifacts of this type exist, they have been found across the site from Mound ET in the east to the north side of Mound AB (refer back to Figure 10.2 for locations). One example was found in the Harappa Period dump that covers part of the cemetery area. Most of the Mari "Diamonds" from secure stratigraphic contexts come from Period 3B or 3C levels, although two that may date as early as Period 2 have been found in mixed deposits on Mound AB. The finds from the later levels provide a small but important piece of evidence suggesting that materials from alabaster deposits of the central Salt Range were still being brought to Harappa during the latter half of the urban phase.

## CHAPTER CONCLUSION

The combination of sulfur and strontium isotope analysis has proven to be an effective method with which to identify the probable geologic sources of Harappan alabaster artifacts. Even though the provenience of some samples in the archaeological set remains ambiguous and there are several important potential geologic sources left to be characterized, many new insights have been gained into the acquisition and utilization of alabaster in northwestern South Asia during the third millennium BC.

Kot Diji Phase (Period 2) residents of Harappa used alabaster from both the Eocene and Infra-Cambrian age deposits of the Salt Range. They may very well have obtained this material through trade with their Early Harappan contemporaries at sites like Rehman Dheri and Musa Khel, which lie in the vicinity of those mountains and have alabaster fragments on their surfaces isotopically analogous to sources found there. At Musa Khel, as at Harappa, materials from each of the two Salt Range alabaster formations were present. This, taken together with the evidence that black chert identical to that found in Period 2 levels at Harappa may have also been brought to Musa Khel from nearby sources (Chapter 6), suggests that the site was an important gathering place or staging area for rock and mineral resources collected from across this region. Its location near the base of one of the major passes through the Salt Range further strengthens this possibility.

New sources of alabaster began to be used at Harappa as society there and elsewhere in the Indus Valley took on a decidedly urbanized character beginning in Period 3. Exploitation of older sources did not cease however. On the contrary, they continued to be used well into the urban phase as evidenced by the presence through Period 3C of both Salt Range alabaster and Mari "Diamonds." Still, most of the alabaster used by urban phase residents of Harappan seems to have come from either the Eocene deposits west and northwest of the site in the Sulaiman Range and Kohat regions or from the as yet unidentified source(s) characterized by highly radiogenic strontium. That source(s) very likely

lies somewhere in the western Himalayas (possibly Jammu and Kashmir) although there is a chance that it could also be related to Eocene deposits in the Salt Range. A few artifacts from Harappa and the vessel fragment from Mohenjo-daro suggest that consumers in the Indus Valley at this time had at least limited access to still other sources.

The results of this study also suggested that some intra-site differences may have existed at Harappa in terms of the acquisition and utilization of alabaster. For example, all alabaster analyzed from Mound F comes from deposits in the Sulaiman Range. Craftspeople on Mound AB also utilized Sulaiman alabaster as well as raw material from both of the Salt Range formations. A slightly different pattern of acquisition and production was left by people residing in the eastern half of the site. Residents of the adjoined mounds E and ET were apparently the only ones at the site producing and consuming alabaster bangles. In addition they seem to have been the sole group with either access to or the desire to work material from the "unknown" alabaster source with unusually high levels of radiogenic strontium. Similar site-wise variations in raw material procurement and/or utilization have been observed between the major mounded areas at Harappa for grindingstone (Chapter 5) as well as for vesuvianite-grossular and "Ernestite" (recall the discussion in Chapter 9).

The amount of alabaster manufacturing debris that is evident at Harappa may not reflect the scale of production there as well as a material like agate does for the bead making industry. The reason is that the waste produced by working a material like agate is generally of little further use and so all or most of it remains in the archaeological record as evidence of that activity. Gypsum, on the other hand, had a very broad range of uses in the ancient world (Levey 1958). Consequently, a large portion of the debris generated during the making of alabaster objects at Harappa may have been collected and used for other purposes that are less detectable archaeologically, thus leaving a much diminished record of production. Even if this was the case, however, the ubiquitous presence of this material across the site and throughout its chronological sequence, when combined with the evidence that multiple sources were at times exploited to meet supply needs, strongly suggests that alabaster working was one of the more important lithic industries at Harappa.

Lastly, although it impossible to know for certain in what sizes Harappans typically transported raw alabaster from the sources identified here, it is stands to reason that the pieces of stone brought to the site for creating objects such as dishes and bowls were significantly larger and heavier than the thin-walled finished products that are found. The best piece of evidence currently available is the large ringstone fragment pictured in Figure 10.4 C, which weighs approximately two kilograms. When that artifact was complete it probably weighed no less than 10 kg. It is therefore possible to state that Harappans (or the people who were supplying them) were capable of transporting raw alabaster of at least that size from certain source areas. With regard to this particular artifact that source appears to have been west of Harappa in the Sulaiman Range. Pab sandstone grindingstones of that size and greater came from the Sulaiman Range (Chapter 5) and so it is not at all surprising that other materials were also transported in bulk sizes from that region.

In the next chapter, I identify and trace the acquisition networks for several distinctive varieties of limestone that were used to make, among other things, the largest type of stone objects found at Harappa – ringstones.

# CHAPTER 11

# LIMESTONE ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: LIMESTONE

Limestone – a massive rock predominately composed of calcium carbonate – was, on the whole, used to create objects larger than are typically found at Harappa. Some of those objects are "ringstones" and other big pieces of carved rock that probably had some architectural and/or ritual-symbolic purpose. Large pieces of limestone were also evidently acquired for utilitarian purposes, such as the blocks probably used as sewer drain covers. Like grindingstone (Chapter 5), the heavy and unwieldy nature of comparatively large stone artifacts such as these makes examining them especially useful for detecting subtle and sometimes not so subtle, changes in the ability and/or desire of ancient peoples to acquire difficult-to-transport heavy stone resources. In addition, the likelihood that some of these large objects were important ritual or prestige-related items provides another dimension with which to examine the ways in which social power was expressed through the consumption and display of stone.

Using ICP-AES supplemented by ICP-MS and INAA, I compare 107 limestone artifacts from Harappa (roughly half of the site's assemblage for this material variety) to 160 geologic samples collected from multiple locations in six limestone-bearing geologic formations in Pakistan and India. It is revealed that, mainly during Period 3C, Harappans acquired large limestone objects from multiple sources, some as far away at Kutch in Gujarat. This chapter commences with a discussion of the kinds limestone artifacts found at Harappa and other Indus cities. I then provide details on the material properties and possible geologic sources of the five different limestone types most commonly used to make large objects at Harappa. The primary method that was used to characterize artifacts and geologic source material is new and somewhat experimental (Law and Burton 2006b). I therefore present the provenience results in the same exploratory, step-by-step manner in which the data were obtained and evaluated. The implications that the provenience determinations made here have on our understanding of long-distance trade, inter-regional interaction and changing expressions of prestige and power at Harappa is discussed in the summary section that concludes this chapter. Regions, sites and sources mentioned in this chapter are identified in Figures 11.1, 11.14 and 11.16.

## LARGE LIMESTONE OBJECTS AT HARAPPA AND OTHER INDUS CITIES

Around 95% of the objects in Harappa's rock and mineral artifact assemblage are small in size and light in weight. Grindingstones composed of sandstone-quartzite or igneous and metamorphic rocks make up most of the five percent or so of objects that weigh more than one kilogram. After grindingstones, nearly all remaining artifacts in the bulk size/weight category are composed of limestone.

Small ring-shaped objects (whorls, mace-heads, etc.) made from various kinds of stone are not uncommon at prehistoric sites in northwestern South Asia. Large-sized "ringstones" (some weighing over 100 kg) made of limestone, however, are a category of artifact that seems to be exclusive to Indus

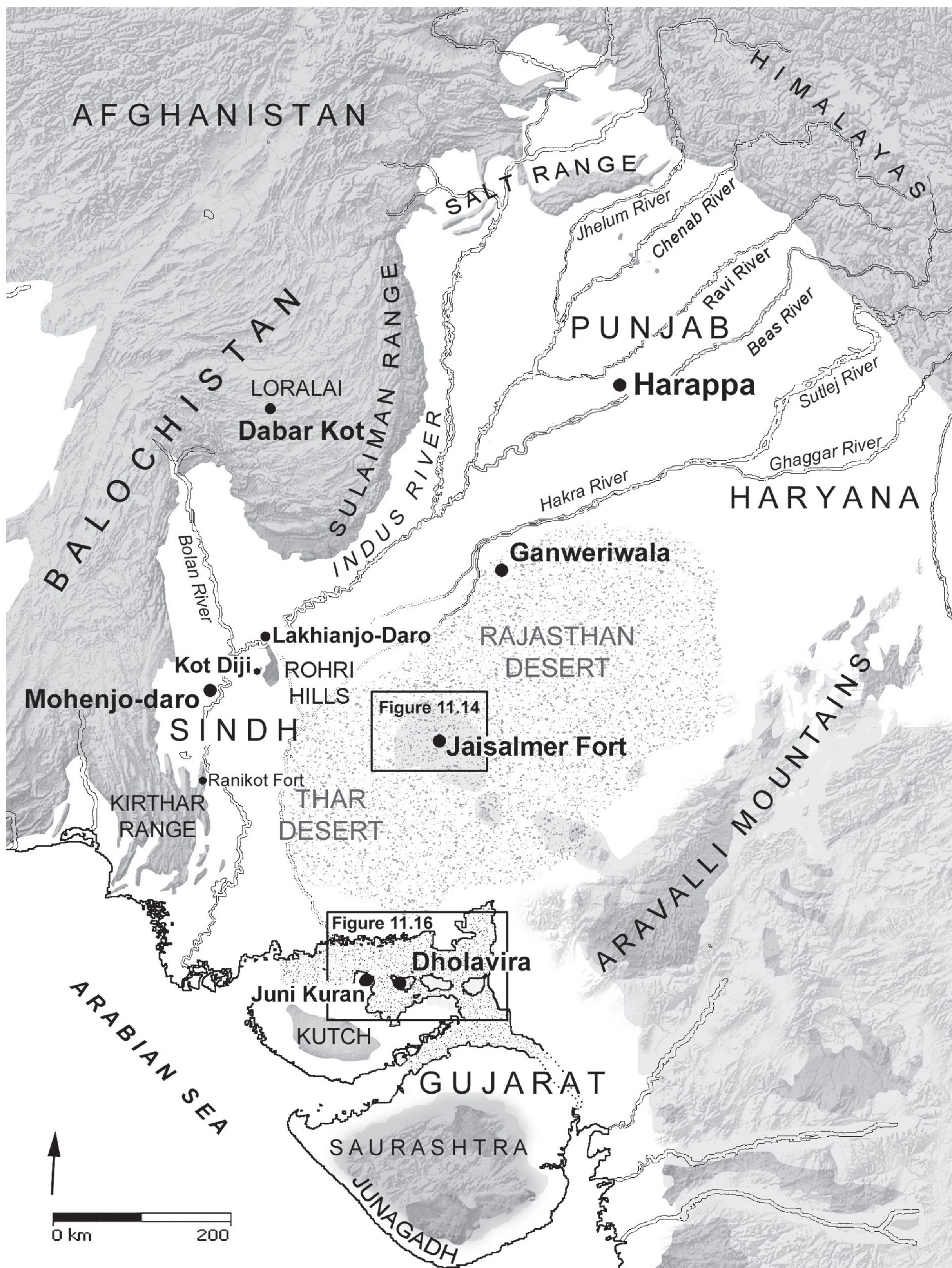



**Figure 11.1** Sites and regions discussed in this chapter.

Civilization cities (Dales 1984). The styles in which they were carved and types of limestone from which they were made from seem to differ somewhat from site to site. The "typical" ringstone at Harappa has an undulating (or wavy) top and base with a large central hole and is most often composed of a light yellow micritic (microcrystalline) limestone (Figure 11.2 A and B). Ringstones found at Mohenjo-daro are




**Figure 11.2** **[A]** Large wavy ringstones at Harappa in front of the tomb of Baba Noor Shah (Naugaza). **[B]** Three ringstones excavated in 2010 west of Baba Noor Shah's tomb. **[C]** Flat-topped micritic limestone ringstones from Mohenjo-daro. **[D]** Ringstones from Dholavira on display in the National Museum, New Delhi.




**Figure 11.3** Mould terracotta tablets from **[A]** Mohenjo-Daro and **[B]** Lakhan-Jo-Daro that appear to depict composite columns with flat-topped ringstones.



**Figure 11.4** Two large conical objects from Harappa composed of white porcelaneous limestone. Harappa Museum Reserve Collection. Note - 10 cm increments on the scale.




**Figure 11.5** Left - Drain at Mohenjo-Daro covered with limestone blocks. Right - Three large rectangular limestone blocks from Harappa. Harappa Museum Reserve Collection. Note - 10 cm increments on the scale.

usually made of a cream-colored micritic limestone and have a flat top and base with a large central hole (Figure 11.2 C). Examples from Dholavira are made from a sandy-textured yellow and reddish-brown banded limestone, have flat tops and bases with small central holes and can have either concave or convex midsections (Figure 11.2 D).

The function of these large ringstones has been disputed. They have been variously interpreted as Shivite "yoni" stones (Marshall 1931d: 58-60), astronomical "calendar stones" (Maula 1984) and ceremonial stones associated with cultic tree-worship (During-Caspers and Nieskens 1992: 94). However, it now seems as if Mackay's suggestion (1938: 597) – that the ringstones found at Mohenjo-daro were elements of composite columns made of stone and wood – is the correct one. In the southern gateway of the citadel at Dholavira, complete ringstones have been found in positions that strongly suggest they were the bases of pillars (Bisht 1989b). Recently, Vidale has pointed out (2010) several examples of moulded terracotta tablets from Mohenjo-Daro that depict column-like objects made up in part of stacked elements that, for all appearances, are identical to the flat-topped ringstones found at that city (Figure 11.3 A is an example taken from Shah and Parpola 1991). In early 2010, another moulded terracotta tablet was recovered during the excavations at large Indus site of Lakhanjo-Daro. That artifact (which is reproduced in Figure 11.3 B with the kind permission of Dr. Qasid Mallah, Chairman, Department of Archaeology, Shah Abdul Latif University, Khairpur) depicts a composite column made up of what appears to be the trunk of a palm tree (note the wavy concentric pattern) topped off with two flat-top ringstones and a capital with prominent volutes. After seeing the Lakhanjo-Daro tablet, Dr. Mark Kenoyer suggested (*personal communication* 2010) that the wavy ringstones of




**Figure 11.6** Unusually shaped red, gray and yellow limestone artifacts from Sahni's excavations (Trench "B") on the north side of Mound AB. Harappa Museum Reserve Collection.

Harappa might have been stacked upon one another in order to mimic the pattern of a palm trunk.

Large conical objects that are frequently composed of limestone have been also found at Harappa, Mohenjo-daro and Dholavira. Such artifacts are usually interpreted as "phallic emblems" or *lingams* (Marshall 1931d: 58-61) although some may have actually been grindingstones (Mackay

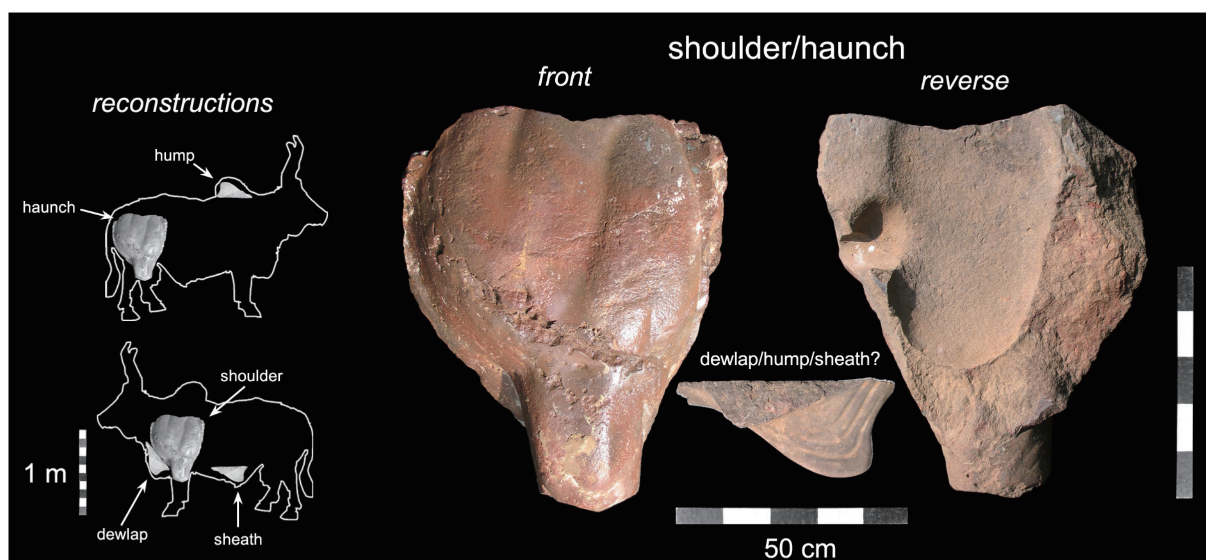



**Figure 11.7** Fragments belonging to composite sculpture of a bovid (bull?) from Sahni's excavations on the northeast corner of Mound AB.

1938: 407) or even doorstoppers (R.S. Bisht *personal communication* 2007). Two examples composed of a white, porcelaneous limestone are stored in the Harappa Museum's Reserve Collections (Figure 11.4) and may be the ones mentioned by M.S. Vats in a footnote (1940: 51) as having been recovered in excavations trenches in the central to southern part of Mound AB.

A number of fragmentary as well as several complete large rectangular limestone blocks (Figure 11.5 *right*) from past excavations are stored in Harappa Museum's Reserve Collection. It is possible that these objects were drain covers similar to the ones used at Mohenjo-daro (Figure 11.5 *left*).

A series of red, gray and yellow limestones objects (a selection of which can be seen in Figure 11.6) that may be architectural elements have been recovered on the northeast part of Mound AB. During the excavations of the 1920s, these artifacts were discovered (along with cones and ringstones) by R.B.D.R. Sahni in Trench "B" in levels that would probably be equivalent to Period 3C because of their association with pointed-base goblets (Vats 1940: 139). Many of the objects are fragmentary blocks that are carved with decorative, concentric grooves on one side. On the reverse sides of some pieces there are holes or sockets that may indicate they were meant to be inserted or affixed onto something as if part a molding or composite stone facade. More examples of these unusually shaped fragments were recovered in Period 3C levels in the same general area (Trench 39) during the 1998 season of the HARP (Meadow *et al* 1998: 6). As far as I can tell this particular kind of stone object is unique to Harappa, to this area of the site and to this period. Their presence suggests that a structure or structures heavily adorned with stone may have existed in this part of the city.

In January of 2004, Prof. Mark Kenoyer and I had the opportunity examine the aforementioned large stone artifacts from Sahni's excavations on the northeast corner of Mound AB, which are stored in the Harappa Museum's Reserve Collection. Among them is an object (Figure 11.7) that is recorded as a "block of gray sandstone roughly resembling a (?) tortoise-shell" (Vats 1940: 139, Plate CVXII 8). After closer examination it appears that it is actually a fragment from a life-sized composite statue/frieze of a large bovid, most likely a bull. It is difficult to tell with certainty whether or not the piece represents the front shoulder portion of the animal or its haunch (I have shown the two possible reconstructions on the left hand side of Figure 11.7) but the shaft of a

leg descending from the muscled body is clearly evident. During this same field season, a workman at the site brought to Prof. Kenoyer's attention a sculpture fragment that he had found in the modern cemetery at the base of Mound AB, directly below where Sahni's excavations had been. This fragment, which was made of the same type of reddish gray-colored stone that I call "gray sandy limestone" (discussed below), may represent a bull's dewlap, a hump or sheath (see possible reconstructions on Figure 11.7). Also, in the 1940 report but not in the Reserve Collection is another object from Sahni's excavations on the northeast corner of Mound AB, which is described as a "hoof" (Vats 1940: 141, Plate LXXXIII 36). At around 17 cm in length, this "hoof" (if that's what it is) would be roughly proportionate with the other two pieces. Of course, it cannot be certain that these fragments are all part of the same sculpture/frieze. No information on the context of the dewlap/hump is available and, although they were found in the same general area, the "hoof" and the shoulder/haunch were recovered in different "stratum" (note that the "stratum" and "depth" recording system used during the 1920s excavations makes it difficult to accurately judge the chronological relationships). Although the position of Sahni's excavation trench suggests that they could come from late Period 3C levels, it is Prof. Kenoyer's opinion (Kenoyer *in press* a) that the pieces date to the Mauryan Period (ca. 4th to 2nd century BC) or slightly earlier. Regardless of their age, the shoulder/haunch piece alone, at 126 kg, is the second heaviest stone objects (made of limestone or otherwise) ever found at Harappa. Only one ringstone from the site is heavier.

In the following section, I examine the major types of limestones used to make the various large objects discussed above as well as the potential sources for those types.

## TYPES OF LIMESTONE USED AT HARAPPA AND THEIR POTENTIAL SOURCES

Limestone is a highly variable rock both compositionally and visually. It is, in addition, widely available in most of the geologic formations surrounding the Indus Basin. For these reasons it may seem that identifying the sources from which Harappans obtained this material variety would be highly problematic, if not impossible. However, as in the case of grindingstones (Chapter 5), a close examination of limestone artifacts indicates that several distinctive material *types* exist within the overall assemblage. Macroscopically some of these types seem to correspond with stone found in a limited number of geologic formations around the Greater Indus region. Although it may not be possible without extensive sampling and analysis to discover the precise location (as in a specific quarry) that one of these distinctive limestones types came from, geochemical characterization can enable us to state, with a reasonable degree of confidence, which of two or more geologic formations an artifact more than likely was derived from.

In this section I discuss the major types and potential sources of the limestones used to make large objects at Harappa. Approximately 200 limestone artifacts have been tabulated since excavation by the HARP recommenced in 1986 and many more from past excavations are stored in the Harappa Museum's Reserve Collection. The types that are discussed in this section were defined based on macroscopic properties of the artifacts alone. Details regarding the texture and color (as determined using a Munsell Rock Color Chart) of all of the archaeological samples analyzed in this study are provided in Appendix 11.1. For that appendix, the macroscopic type names were shortened and noted in uppercase letters - BANDED, GOLDEN, GRAY, MICRITIC and WHITE.

### Sandy limestones

The material for a great many of the artifacts that I examine in this chapter was recorded, not incorrectly, as "sandstone." As noted in Chapter 4, limestones are sedimentary rocks that are highly variable compositionally. The geological convention is to call a rock limestone if it is composed of 50% or more calcium carbonate (Rapp 2002: 250). Some types have so much silica that they are essentially a mixture of sandstone and limestone (Lambert 1997: 24). Although no whole rock analyses have been conducted to determine the exact proportions of the major mineral constituents of any of the geological or archaeological samples examined this chapter, I can say that the materials comprising the datasets are quite variable. Within both Harappa's "limestone" artifact assemblage and the various individual geologic formations that I visited and sampled for this portion of the current study, there are a full range of materials that could be called sandstones, "calcareous" sandstones (containing a high amount of calcium carbonate), "siliceous" limestones (containing a high amount of silica) or just plain limestones. For the sake of simplicity, I refer to all of those with moderate to high silica contents as "sandy limestones."

#### *Banded yellow-brown and yellow-brown sandy limestone (BANDED)*

In January of 2004, two large ringstones stored in the reserve collection of the Harappa Museum were briefly removed for conservation purposes (Figure 11.8). The smaller of the two ringstones may be the one that the excavator M.S. Vats described as coming from the center of the old Harappa Police Station on Mound ET (1940: 140 & Plate CXVII, 3). Although we do not currently know where on the site the larger one was found, they are both clearly of Harappan design – albeit apparently not a local one. Vats noted (ibid.) that the ringstone found at the old Police Station lacked the wavy undulations typical of those found at Harappa but was similar in style to the flat-topped ones found at Mohenjo-daro (Sahni 1931a: 191). While cleaning these artifacts it was possible to closely examine the material from which they were made, which was a sandy textured limestone that had yellowish orange with pale brown to red-brown banding or patches. At Mohenjo-daro, a ringstone is on display (Figure 11.9) that is identical in style and material as the two banded ones from Harappa. It is possible that these unusual flat-topped ringstones were created at that city and then brought to Harappa. However, in addition to the ringstones, fragments and smaller artifacts made of the same "banded yellow-brown" sandy limestone have been recovered (Figure 11.10). If the fragments represent manufacturing debris (they may actually just be broken pieces of larger artifacts) then it could mean that this type of limestone was brought to the site in large unmodified blocks.

#### *Bright yellow-red sandy limestone (GOLDEN)*

Another type of limestone at Harappa with a sandy texture has a distinctive bright yellow, at times "golden" color and is frequently mottled with red or pink patches. Harappans created objects of all descriptions from this stone including wavy ringstones (the largest piece and several of the fragments in Figure 11.11 are clearly from ringstones) and architectural elements (the first left and center objects in Figure 11.6). When past and present excavators at Mohenjo-daro and Harappa encountered artifacts made from this material they often used the term "Jaisalmer" stone (see below) to describe them (Marshall 1931c: 31; Vats 1940: 140, 358; Meadow *et al* 1998: 6).

#### *Gray-red sandy limestone (GRAY)*

The final major type of sandy limestone used at Harappa is gray to grayish-red in color and can occasionally have an almost crystalline texture. This type was used to make architectural elements (see the examples on Figure 11.6, bottom and center right), the



**Figure 11.8** Large banded flat-topped ringstones (HLS-007 and HLS-008) from Harappa.



**Figure 11.9** Flat-topped banded limestone ringstone from Mohenjo-daro.




**Figure 11.10** Fragments and broken miniature ringstone (far right) composed of banded yellow-brown and yellow-brown sandy limestone.

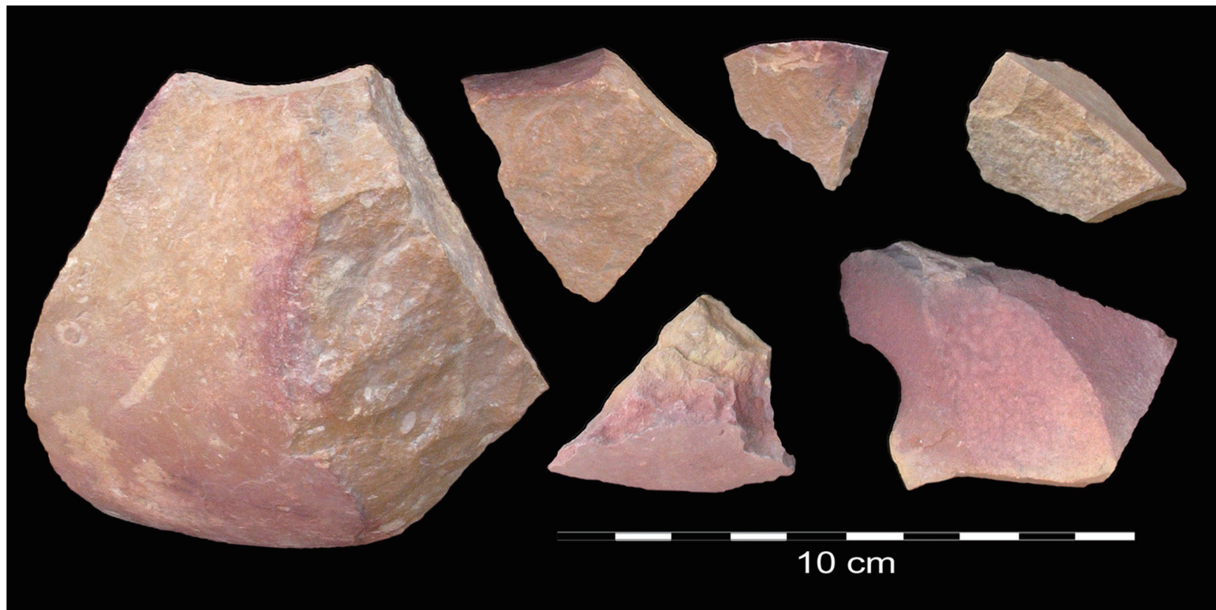



**Figure 11.11** Ringstone pieces and miscellaneous fragments composed of bright yellow-red sandy limestone.




**Figure 11.12** Ringstone pieces and miscellaneous fragments composed of sandy gray limestone.

bull sculpture pieces (Figure 11.7) and wavy ringstones (Figure 11.12). Of the three sandy limestones this one appears to have the highest silica content. Some examples of this material, which probably more appropriately described as "calcareous" sandstone, are moderately fossiliferous and.

*Three possible source formations for the sandy limestones used at Harappa*

A review of the geologic literature indicates that there are few formations surrounding the Indus Basin where sandy limestone with these precise textural and visual characteristics can be found, either separately or together. Although extensive bodies of limestone exist in the Himalayas, the Salt Range and regions west of the basin, the material found in those tends largely to be fine grained, micritic or porcelaneous in texture. There are three regions on the margins of the lower Indus Basin, however, where visually varied deposits of sandy textured limestones (or calcareous sandstones) are known to occur.

The closet of the regions is an area of low



**Figure 11.13** The "Golden" city of Jaiselmer and details of its limestone architecture.

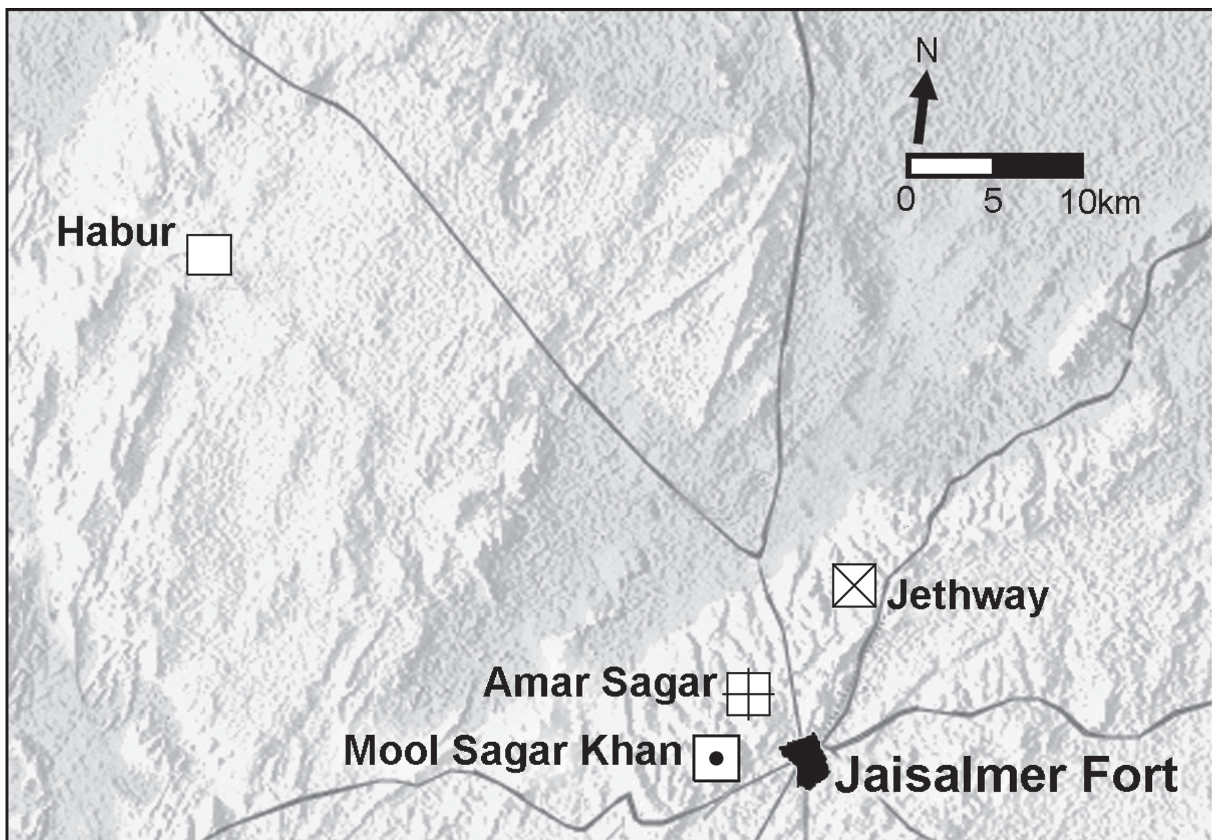



**Figure 11.14** Limestone outcrops in the vicinity of Jaisalmer Fort, western Rajasthan that were sampled for this study.

broad plateaus that rise out of the desert sands of western Rajasthan, India. The limestone deposits of Jurassic age that occur in this region have long been exploited as a source decorative building stone (Agrawal *et al.* 1999: 22-24). Here, 450 km south-southwest of Harappa, sits the city of Jaisalmer, famous for its golden-hued architecture (Figure 11.13). Four locations in the region were sampled for

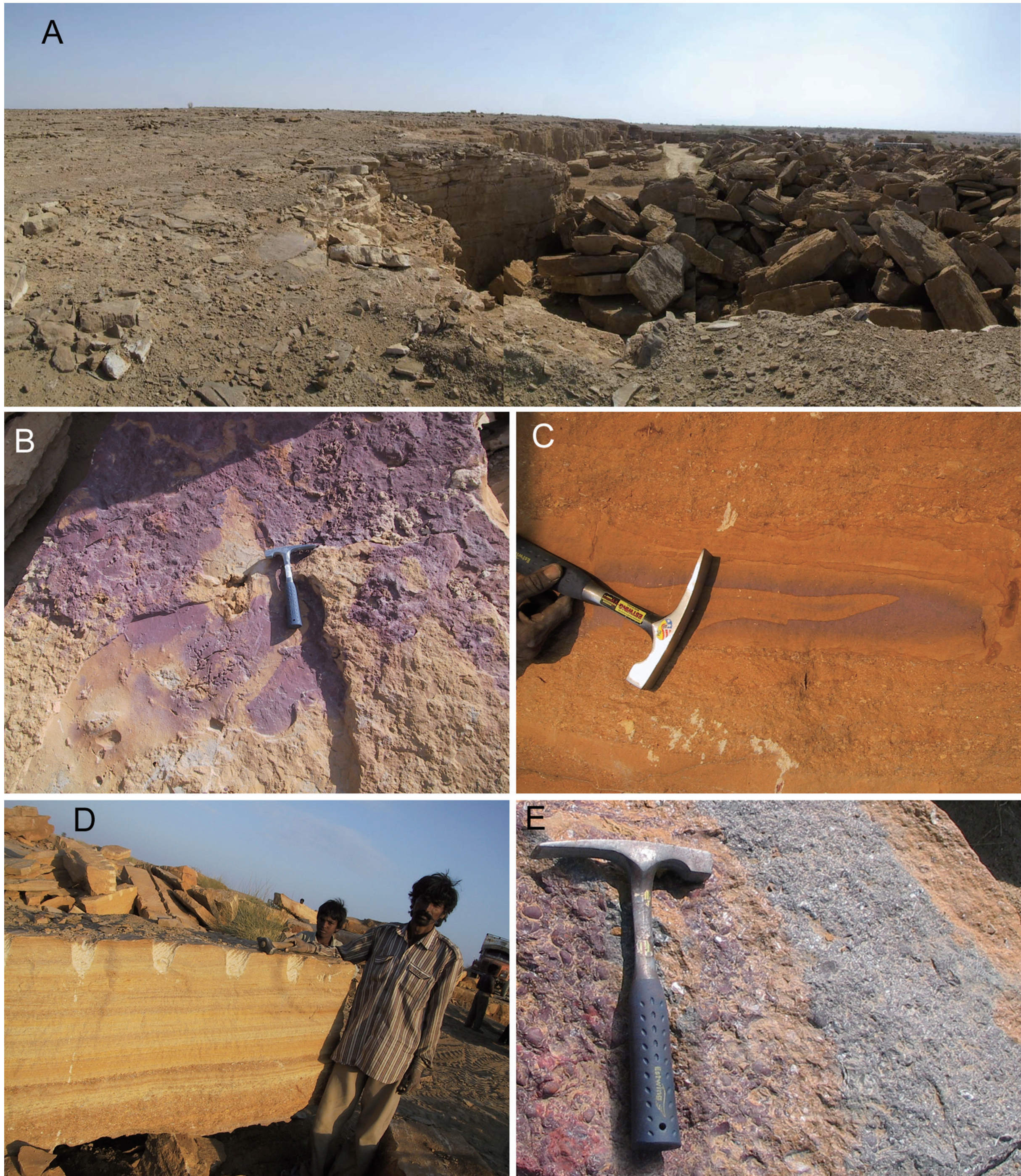



**Figure 11.15** Jaiselmer area limestone occurrences. **[A]** Mool Sagar Khan quarry. **[B]** Detail of bright "golden" yellow Jaisalmer limestone with red patches at Mool Sagar Khan. **[C]** Detail of reddish banding in the limestone at Amar Sagar. **[D]** Banded sandy limestone being quarried at Jethway. **[E]** Gray, yellow and red sandy limestone at near Habur, 45km northwest of Jaisalmer Fort.

this study (figures 11.14 and 11.15). The quarries that were exploited for much of the distinctive bright yellow-red sandy limestone used to build the city are found within 10 km of Jaisalmer Fort at Mool Sagar Khan ("MSK") and nearby Amar Sagar ("AS"). Similar material is also found north of the city near Jethway along with a banded yellow-brown type that moderately resembles the banded type found at Harappa. Beginning around 45 km west of Jaisalmer Fort at Habur are limestone outcrops that, although sandy in texture, are more fossiliferous and crystalline. Pockets of gray to gray-red material are found here,

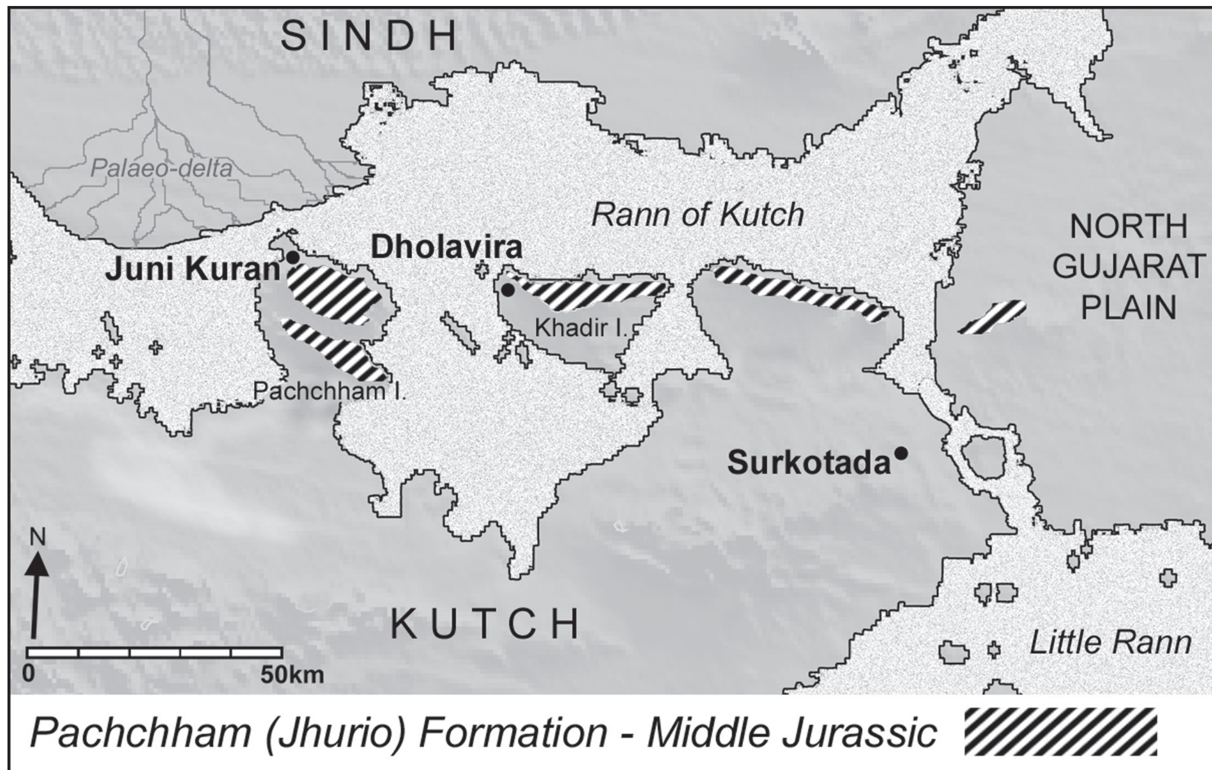



**Figure 11.16** Archaeological sites and Pachchham limestone outcrops in northern Kutch.



**Figure 11.17** Sandy yellow banded Pachchham limestone masonry and slabs in the northern gateway of Dholavira's citadel.



**Figure 11.18** Banded Pachchham limestone quarry 3 km north of Dholavira. Bottom left – Discarded ringstone rough-out. Bottom right – discarded slab.

along with yellow-red types, which are somewhat similar in appearance to the gray sandy artifacts from Harappa – especially the ringstone fragments.

W.T. Blanford noted in his geological survey of western Sindh that stone from the Ranikot beds of the Kirthar Range "closely resembles the very beautiful Jurassic limestone procured at Jaisalmer" (1879: 194). This second potential source formation lies approximately 700 km southwest of Harappa but only around 100 km from Mohenjo-daro. A few small samples were collected for this study near Ranikot Fort.

A third potential source region for sandy limestone is located nearly 800 km south of Harappa. The Pachchham limestone (Figure 11.16) formation of Jurassic age (Fuersich 2001) is exposed



**Figure 11.19** Gray Pachchham limestone near the Harappan site of Juni Kuran, Kutch.




**Figure 11.20** Miscellaneous small micritic limestone objects and non-diagnostic fragments from Harappa.




**Figure 11.21** Top – White porcelaneous limestone fragments from Harappa. Bottom – White porcelaneous limestone of the Pahr Formation, Loralai District, Balochistan.

on several islands located within the intermittent inland sea known at the Great Rann of Kutch. The southernmost Indus city of Dholavira is located on one of these islands called Khadir (Bisht 1991). Unlike at other Indus cities, stone is used here not only for the gateway ringstones (Figure 11.2 D) that so resemble the two flat-topped ones from Harappa, but also for the city's walls (Figure 11.17), stairs,

houses, drains, wells and other public works. Much of this stone seems to have come from a Harappan period quarry (Figure 11.18) located three kilometers directly north of the site (R.S. Bisht 2003 *personal communication*). The Pachchham limestone at this point ("quarry") and at nearby Limdiwali Tari ("LT") is sandy textured and has yellow-brown with reddish-brown bands – again, visually identical to the two ringstones from Harappa. Most significantly for this study are what appear to be ringstone 'blanks' that were discarded during the roughout process (note the large crack splitting the ringstone blank pictured in the *bottom left* image of Figure 11.18). Several of these roughouts as well as discarded slabs (Figure 11.18 *bottom right*) have been found within the kilometer long quarrying area.

Around 45 km west-northwest of Dholavira across the Rann on Pachchham Island lies the Harappan period site of Juni Kuran. Recently excavated by the Archaeological Survey of India (Pramanik 2005), this site appears much like a smaller version of Dholavira, with a rectangular stone perimeter wall and a "citadel" with gateways in which ringstones have been found. The Pachchham limestone in this part of Kutch tends to have a more sandy crystalline texture and, in addition to yellow brown material, there are gray types (Figure 11.19) somewhat similar in appearance to the gray sandy limestone artifacts of Harappa.

### Micritic and white chalky-porcelaneous limestones (MICRITIC and WHITE)

Microcrystalline and fine-grained limestones of various colors ranging from white to dark yellow-brown were used by Harappans to create many different kinds of objects both small (Figure 11.20) and large. The two main kinds of large-sized micritic limestone artifacts – wavy ringstones (Figure 11.2 A, B and C) and the rectangular blocks that may be drain covers (Figure 11.6 *right*), have already been mentioned in preceding sections. The potential sources of this type of material are far too numerous to be mentioned in detail. The closest and most accessible geologic formations containing limestone of this type would have been either those of Eocene age found in the Sulaiman Range or the Permian to early Eocene formations of the Salt Range (Bender 1995b: Table 9.4). The Eocene Rohri Hills in Sindh are another possible source.

Only a small number of limestone artifacts over all have been found at Harappa that are made of chalky white to porcelaneous white limestone. The two large conical objects (Figure 11.4) described above and a half dozen or so fragments (Figure 11.21 *top*) represent most of that sub-assemblage. Limestone formations of this kind, although still widespread, are comparatively less common than the micritic ones. In Balochistan, white porcelaneous Parh limestone (Figure 11.21 *bottom*) can be found from the Loralai District in the north part of the state to the Kirthar Range in the south (Ahmad 1969: 104). Chalky white limestone is found in the upper part of Laki Formation of southern Sindh (Jafry and Ahmad 1991; Fatmi and Khan 1998).

### Section summary

Many of the large objects created or acquired by residents of Harappa were composed of limestone. The principal types they used were sandy limestone (banded yellow-brown, bright or "golden" yellow-red and gray-red), micritic limestone (of varying shades) and white chalky-porcelaneous limestone. Identifying the regional source(s) of the latter two might prove difficult due to the wide geographic extent across which limestones of those types occur. However it may be possible to determine which of two potential geologic formations is the most probable source of the sandy limestone artifacts found at the site. The Jaisalmer formation is by far the closer of the two possible source areas to Harappa. However, the nearest Indus Civilization sites to that formation lay approximately 150 km away across the desert in

either Cholistan (Mughal 1997) or the Thar region of eastern Sindh (Mallah 2000). On the other hand, although Kutch is almost twice as far away from Harappa, there is indisputable evidence that the ancient Indus peoples living in that region exploited the local limestone of the Pachchham formation. Transporting heavy pieces of stone (the larger of the two flat-topped banded ringstones found at Harappa weighs 135 kg) from Kutch to the Punjab, however, would have certainly been a difficult and costly undertaking. In the following section I attempt to shed light on this problem through comparative elemental analyses of limestone artifacts and geologic source materials.

## GEOLOGIC PROVENIENCE STUDIES OF HARAPPAN LIMESTONE ARTIFACTS

### Past studies, choice of instrumentation and presentation of data

In recent years there have been numerous geologic provenience studies of limestone artifacts, sculpture or building materials. Some studies have employed atomic absorption spectrometry (AAS) in combination with carbon and oxygen isotope analysis (DeVito *et al*. 2004). Others researchers have made petrographic thin-sections of limestone samples and matched them to geologic formations of the same age through palaeontological analysis of microfossils in the stone (Capedri *et al*. 2001). Studies using INAA have been particularly successful in characterizing quarries and sourcing limestone sculpture and building stone in Western Europe (Holmes and Harbottle 2003). Most recently, a geologic provenience study of limestone artifacts and sources using electron paramagnetic resonance (EPR) spectroscopy yielded promising results (Polikreti *et al*. 2004).

Each of the above methods is destructive at some level and has its own particular strengths and weaknesses. For this study of Harappan limestone artifacts and their potential sources, the choice to use the inductively-coupled plasma spectrometers as the primary tools for analysis was largely based on access to those instruments at the LARCH and the experience of Dr. James Burton in using them. To my knowledge no one prior to this time had used ICP-MS or ICP-AES to source archaeological limestone and so the process of analysis was very much exploratory and experimental. I have therefore chosen to present the results of this study in a way that illustrates the step-by-step sequence in which the archaeological and geologic datasets were analyzed and the results evaluated.

### The archaeological and geologic limestone datasets

This study began as a small pilot project with a limited number of samples. The materials analyzed for the pilot study, or what I am calling the <u>initial</u> dataset, consisted of six samples of archaeological limestone from Harappa (HLS-001 through HLS-006), 15 geologic samples from two locations near Jaisalmer (JLS-001 through JLS-015) and 15 geologic samples from the Harappan Period quarry near Dholavira (DLS-001 through DLS-015) generously provided to me by that site's excavator, Dr. R.S. Bisht of the Archaeological Survey of India. Five of the archaeological samples were examples of sandy limestones that resembled the geologic source materials. One sample [HLS-003], was a micritic limestone fragment with a texture quite different than the other artifacts or geologic samples in the set. All artifacts are coded using an "HLS" (Harappa limestone) number that corresponds to their official HARP "year/lot-record" numbers listed in the second column of Appendix 11.1.

After the very promising results of the pilot study (discussed below), the number of archaeological and geologic samples was substantially increased. I refer

to this as the expanded sample set. The archaeological set grew to include 107 limestone artifacts. Only very small pieces (≈ .005 g) were required for analysis. Half of the samples were taken from flakes or non-descript fragments. The other half were obtained during the examination and cleaning of objects, such as the ringstones from the Harappa Museum's Reserve Collection. In all cases small chips were carefully removed from already damaged areas (note the broken bottom portion of the smaller ringstone in Figure 11.8).

The expanded geologic set grew to include 60 sandy limestone samples from the four locations visited in the Jaisalmer region of Rajasthan along with 65 samples from three areas within the Pachchham Formation of Kutch. Also added to the geologic set were 25 samples of micritic limestone from the Rohri Hills of central Sindh, three samples of chalky white Parh limestone from the Loralai District of Balochistan, five samples chalky limestone from the Junagadh District of Gujarat and two samples of fine sandy yellow limestone from the Kirthar Range near Ranikot in western Sindh. Specifics as to why limestones from these other sources were added to the set are discussed in more detail below. Descriptions of the all samples comprising the archaeological and geologic datasets along with the results and supporting data related to the various analyses conducted on them can be found in appendices 11.1 through 11.7.

## Sample preparation, analysis and data evaluation

Three separate techniques were used to characterize either all or a portion of the archaeological and geological limestone samples examined in this study: ICP-MS, ICP-AES and INAA. In this section, I discuss only how samples were prepared, analyzed and evaluated using these techniques. Strategies and factors that affected the

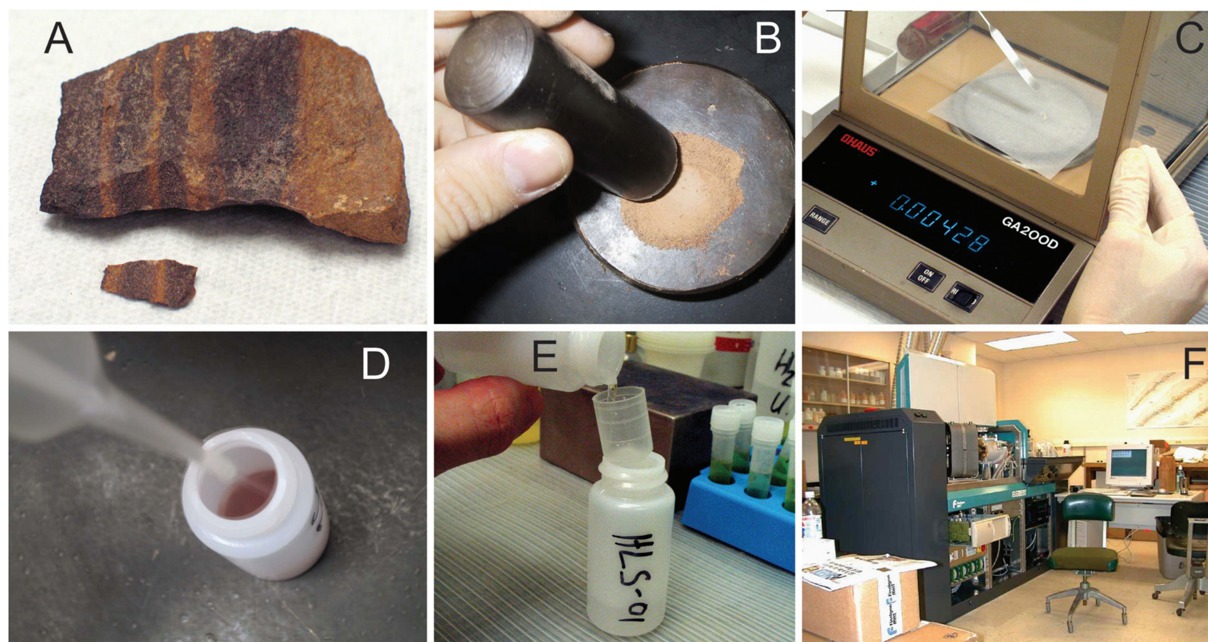



**Figure 11.22** Preparing limestone artifacts and geologic samples for ICP-MS and ICP-AES analysis. **[A]** A chip (≈ 1 gram) is removed from a from a cleaned, freshly broken surface. **[B]** The chip is powdered and the powder is mixed. **[C]** 0.004 g of the homogenized powder is weighed and placed into a plastic vial. **[D]** 1 ml of nitric acid is placed on the sample and left to sit 24 hours. 19 ml of ultra-pure water is then added and the sample is left to sit another 24 hours. **[E]** The sample is then filtered of any undissolved mineral particulates. **[F]** The liquid sample is then analyzed with an ICP-MS or ICP-AES.

choice of instrumentation used are discussed as the results are presented.

Limestone samples needed to be dissolved into solution for elemental analysis using ICP-MS and ICP-AES. Preparing the materials for both instruments was the same (Figure 11.22). For geologic samples this involved the removal of one gram of material from a freshly broken surface using a tungsten carbide drill. Depending on the size and condition of each archaeological sample, either the same procedure was used or a small chip (size > 1 g) of the material was powdered by hand in an agate mortar. For all samples, exactly 0.004g of homogenized powder was weighed out and placed in a polyethylene analysis vial. One milliliter of nitric acid was added to each vial and the samples were left for 24 hours. Only the calcium carbonate components of the limestones were dissolved. Quartz, clay minerals and other non-carbonate constituents of the samples did not dissolve. After 24 hours the samples were filtered of any remaining mineral particulates and 19 ml of purified water was added. In approximately one half dozen cases an archaeological sample contained such a high level of quartz that little or none of it appeared to have dissolved at all. These samples were removed from the archaeological set (this accounts for the occasional skipped HLS sample number in the sequence listed in Appendix 11.1).

Prepared solutions were analyzed using one of the inductively-coupled plasma spectrometers in the LARCH. These instruments are capable of quantifying a wide range of elements at sub-parts-per-million levels. Each element that was measured was divided by measured calcium (Ca). This was done because the large component of quartz in these sandy limestones made it unclear precisely how much calcium carbonate was actually dissolved from sample to sample. Let me provide the following illustration: say for instance that two geologic samples came from the same source but less calcium carbonate was dissolved in one of them due to the fact that it contained a higher amount of silica than the other. In the high silica sample 200,000 parts per million (ppm) Ca and 200 ppm barium (Ba) were measured. In the sample containing less silica 400,000 ppm Ca and 400 ppm Ba were measured. Both samples have ratios Ba/Ca of 0.001. Since equal amounts of material were weighed out for both samples the absolute concentrations of Ba per volume of calcium carbonate actually dissolved is the same in both cases. Dividing all measured elements by Ca in effect serves as an internal standard in the ICP.

The preparation, irradiation and count times for those limestones samples analyzed by instrumental neutron activation (INAA) were precisely the same as for other materials examined for this study using this technique and so are not repeated here (see the INAA method section of Chapter 3).

After being log normalized, the data resulting from the ICP-MS/AES analyses and INAA were evaluated in a variety of manners. Bivariate plotting of two elements (divided by Ca and log normalized) in the dataset obtained by ICP-MS/AES was often sufficient to draw distinctions between geologic sources and determine the probable provenience of archaeological samples. Nevertheless, exploratory canonical discriminant analysis (CDA) was also performed to statistically evaluate the extent to which geologic formations could be distinguished from one another and the degree to which archaeological samples could be assigned to one of them. This method was used to examine data resulting from both ICP-MS/AES analysis and INAA. Issues relating to cross-validation of defined geologic sources (groups) and predicted group membership of archaeological samples were previously discussed in Chapter 3. Appendix 11.6 lists the standardized (canonical) discriminant function coefficients for each of the figures that were generated using CDA.

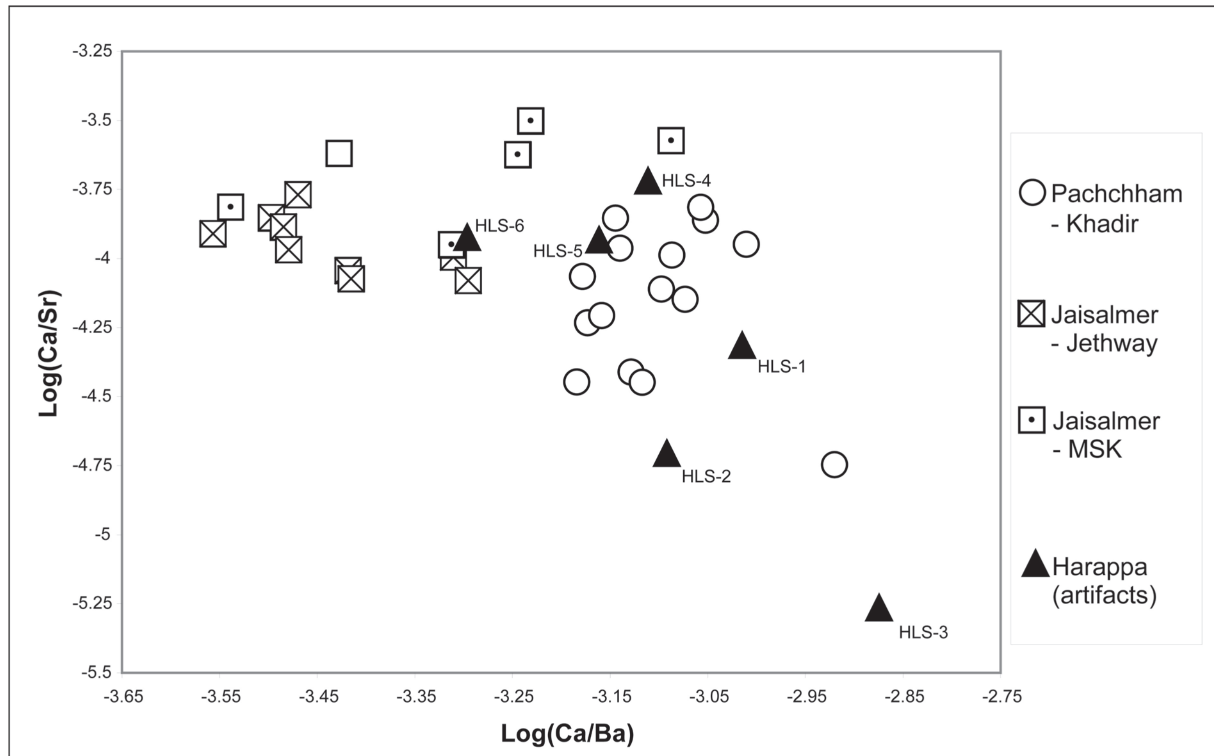



**Figure 11.23** ICP-MS analysis of the initial limestone sample set (bivariate plot).

## Pilot study using the initial sample set

### *ICP-MS analysis of the initial set*

The first analysis of the initial set was performed on the ICP-MS in the LARCH. Concentrations for the elements Al, Ba, Ca, Ce, La, Mg, Mn, Pb, Sr and U were obtained. However, only Ba, Ce, La and Sr were found to be useful for discriminating between the geologic sources. Except for these and Ca, which was needed to standardize the elemental concentrations, data for the other elements were discarded. The concentrations of the elements that were kept are reported in Appendix 11.2.

When the data were examined using simple bivariate plots of two elements (standardized and normalized) it was found that the best separation between geologic sources is achieved using Sr and Ba (Figure 11.23). When the six archaeological limestones from Harappa are superimposed (as black triangles) on that plot several things are suggested. First, it would appear that four of the samples resemble Pachchham limestone even though some of them fell around the margins of that group. HLS-4 in particular also plotted near the edge of the Jaisalmer group as defined by the Mool Sagar Khan (abbreviated MSK on the figures) samples. One sample (HLS-6) appeared more closely related to the limestones from the two deposits in the Jaisalmer region, both of which overlapped significantly. A final Harappan sample (HLS-3) plotted somewhat away from both groups (although closer to the Pachchham samples). This sample, importantly, is the micritic limestone that visually and texturally unlike the other archaeological fragments.

Next, the data were evaluated using CDA in order to get a statistically stronger sense of how different or alike the geologic sources and archaeological samples were (Figure 11.24). For this Ba, Ce, La and Sr values were used after being divided by Ca and log normalized. Good separation between sources was achieved with almost 87% of cross-validated cases in the three geologic groups classifying correctly. In this analysis, the predicted group membership for HLS-6 and HLS-4 (which straddled the margins of the two sources in the bivariate plot) was the Jaisalmer region.

The remaining samples were assigned membership with the Pachchham group. However, we again see that HLS-3 is a distant outlier. Although it is closest to the center of the Pachchham group (and so was predicted to belong to it) it seems to be very unlike either that group or the other archaeological samples assigned to it.

The results of the ICP-MS analysis were very promising. Good separation between sources was achieved and the provenience determinations seemed to be fairly unambiguous, particularly when the data were evaluated using CDA. However, we (Dr. Burton and I) were cognizant of the fact that this method involved only a *partial dissolution* of samples. A large component of these sandy limestones was being discarded during the preparation process and with it data that might potentially yield very different results. It was decided that the results generated using partial dissolution and the ICP-MS could best be validated through a *whole rock analysis* of the initial dataset.

***INAA of the initial set***

A whole rock analysis was performed on the initial sample set using INAA. Of the data that were returned, ten elements (Al, Ca, Eu, Fe, La, Lu, Mg, Mn, Sr and V) that were completely free of missing values were judged to be effective for use in discriminating between sources and assigning provenience to archaeological samples (Appendix 11.3). Due to a problem with the sample changing mechanism at the reactor lab, short count data for JLS-10 was not obtained. Therefore this sample had to be excluded. Elemental concentrations were log normalized before statistical analysis of the data.

Canonical discriminant analysis of the INAA data for the initial set (Figure 11.25) produced results that more or less approximated the data obtained through partial dissolution of samples and analysis using ICP-MS. Only around 65% of cross-validated geologic sample cases were correctly classified due to the large degree of overlap between the two sources in the Jaisalmer Formation. Excellent separation between the two limestone formations was achieved however. Once again the single micritic sample from Harappa was clearly much different from the two sources or other archaeological samples. On the other hand, in this analysis, all of the remaining five samples were predicted to be members of the Pachchham Formation group. This is not entirely surprising as the two samples that had appeared more like Jaisalmer limestone in analyses of ICP-MS data had both plotted near the margins of the two groups of geologic samples.

Hierarchical cluster analysis (Appendix 11.7) indicates that a fair degree of overlap may, nonetheless, exist between the two geologic formations. Numerous clustering strategies were employed (the dendrogram in Appendix 11.7 was generated using median clustering and Pearson correlation) and each time there were invariably cases where archaeological samples that had been assigned to the Pachchham group using CDA appeared to cluster with members the Jaisalmer group. Likewise the clusters generated using the various strategies frequently contained examples from both geologic groups. This *may* indicate that demarcation seen between geologic groups when using CDA is not as sharp as it appears in a plot of discriminant functions.

Overall, however, the INAA results appear to confirm the patterns and provenience determinations suggested by the ICP-MS analysis. Based on this it was decided to significantly expand the archeological and geologic sample sets. Unfortunately at this time the ICP-MS at the LARCH was undergoing an extended period of maintenance. A decision was therefore made to analyze the initial sample set for a third time in order to see if the ICP-AES could be used as effectively as the ICP-MS for geologic provenience studies of limestone artifacts.

***ICP-AES analysis of the initial set***

Details of the detection capabilities of the ICP-

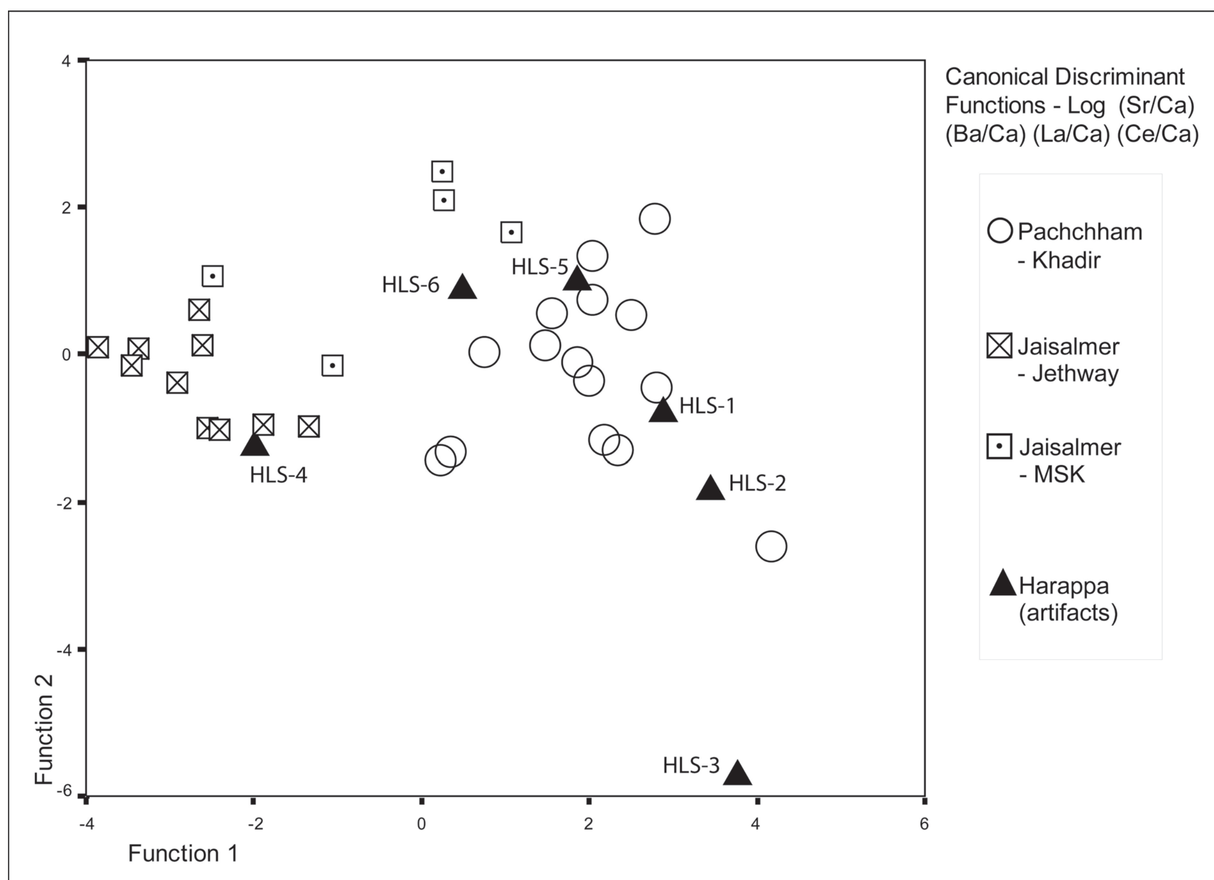



**Figure 11.24** ICP-MS analysis of the initial limestone sample set (CDA).

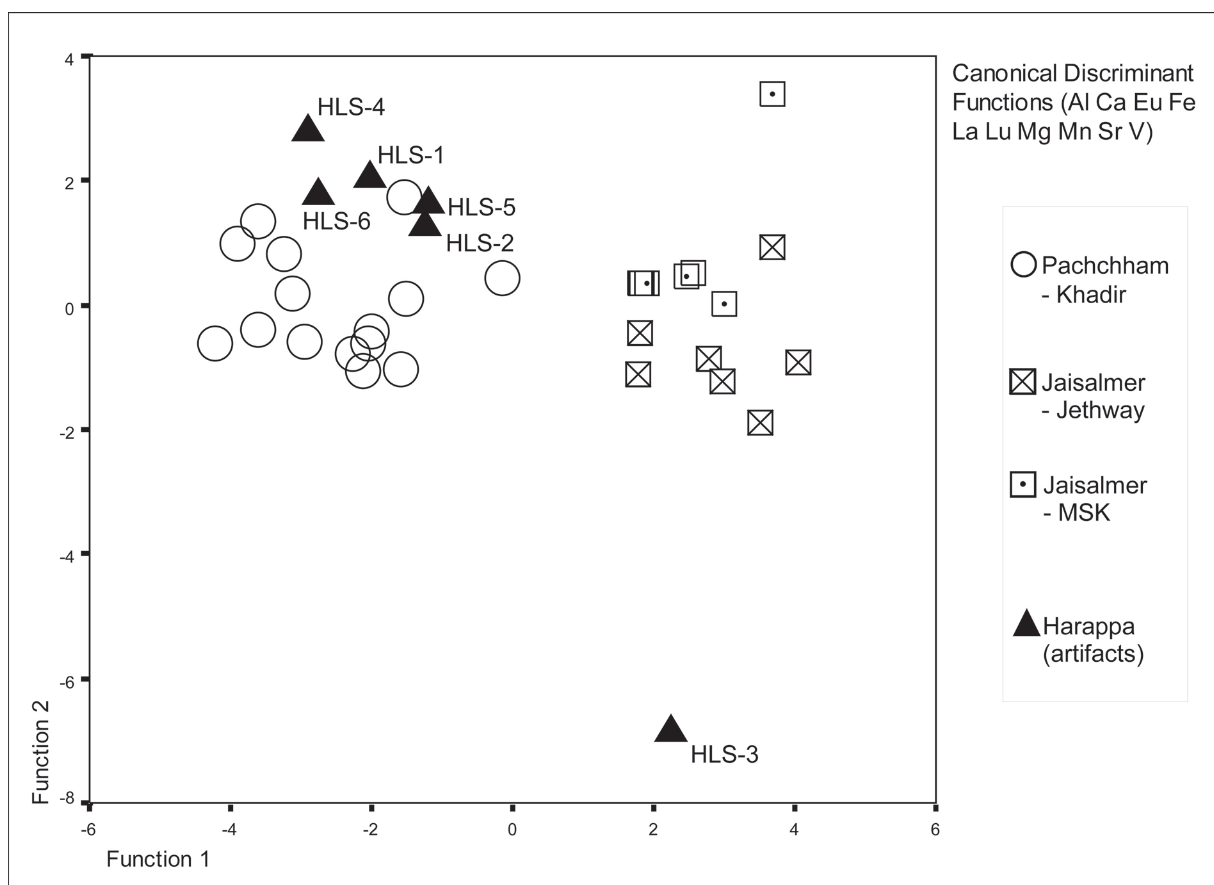



**Figure 11.25** INAA of the initial limestone samples dataset.

AES used for this study were discussed in Chapter 3. Out of the various elemental data provided by this instrument, Ba, Fe, Mg and Sr (in addition to Ca of course) were deemed to be most useful for separating geologic sources and assigning provenience to archaeological samples. The absolute concentrations of the selected elements for these samples are listed in Appendix 11.4.

In a bivariate plot of Sr to Ba (standardized to Ca and log normalized) we see that although there is a degree of overlap between samples from the Pachchham and Jaisalmer formations, two reasonably distinct groups are evident (Figure 11.26). Samples HLS-4, 5 and 6 plot near margins of both groups and HLS-3 is again a distant outlier. A fairly similar pattern for the archeological samples is seen when the results of the ICP-MS analysis (Figure 11.23) were plotted in this way.

A degree of overlap again is evident between the two groups when the four measured elements are used in CDA of the sample set (Figure 11.27). In this instance 67% of cross-validated geologic cases classified correctly. The archaeological samples plotted as ungrouped cases repeat the previously seen pattern with HLS-3 yet again being the single distant outlier. Although the same three samples as before fall near the point of overlap between two geologic groups, the group membership predicted for all of the Harappan limestones (except the outlier) is the Pachchham formation.

In summary, reasonably good separation between the two limestone source formations was achieved using both bivariate plotting and CDA of elemental data obtained with the ICP-AES. Archaeological samples plotted in more or less the same manner using either method of data evaluation. In addition and very importantly, the degree of geologic group separation as well as artifact plotting patterns and/or predicted group membership achieved with ICP-AES derived data were largely consistent with the results from the INAA and ICP-MS studies. Therefore, with a high degree of confidence that the ICP-AES could be used effectively for provenience analyses of limestone artifacts, the sample set was expanded to encompass 107 archaeological samples and 160 geologic samples.

### Analysis of the expanded set using ICP-AES

Analysis using ICP-AES of the 267 samples comprising the expanded set took place over the course of two days. Data for the geologic samples is found in Appendix 11.4. Data for the limestone artifacts from Harappa, as well as listing of the probable geologic proveniences of those samples, can be found in Appendix 11.5.

#### *Comparisons at the level of geologic formation*

I begin the examination of the expanded dataset with comparisons of the Harappan limestone artifacts to source material at the broadest level – that of individual geologic formation. All samples from a single geologic formation are considered as a single group regardless of differences in macroscopic appearance or how far apart they were collected from one another. The Pachchham and Jaisalmer formations are compared with the new group of 25 micritic limestone samples from the Rohri Hills. These samples were collected at the same four locations as the Rohri chert samples analyzed in Chapter 6. It was decided to add this group of Rohri Hills limestone to the set for two reasons: First, over a dozen of the samples in the archaeological set were micritic limestones. Even though there were no samples from other micritic limestone sources available for comparison it would still be informative to know how closely the Harappan samples are to the Rohri limestones. Many Harappan sites, including the city of Mohenjo-daro, are located in the general vicinity of the Rohri Hills. Secondly, in order to create a broad-scale display of data points on an *x-y* axis using CDA a third group was needed in order to generate a second discriminant score.

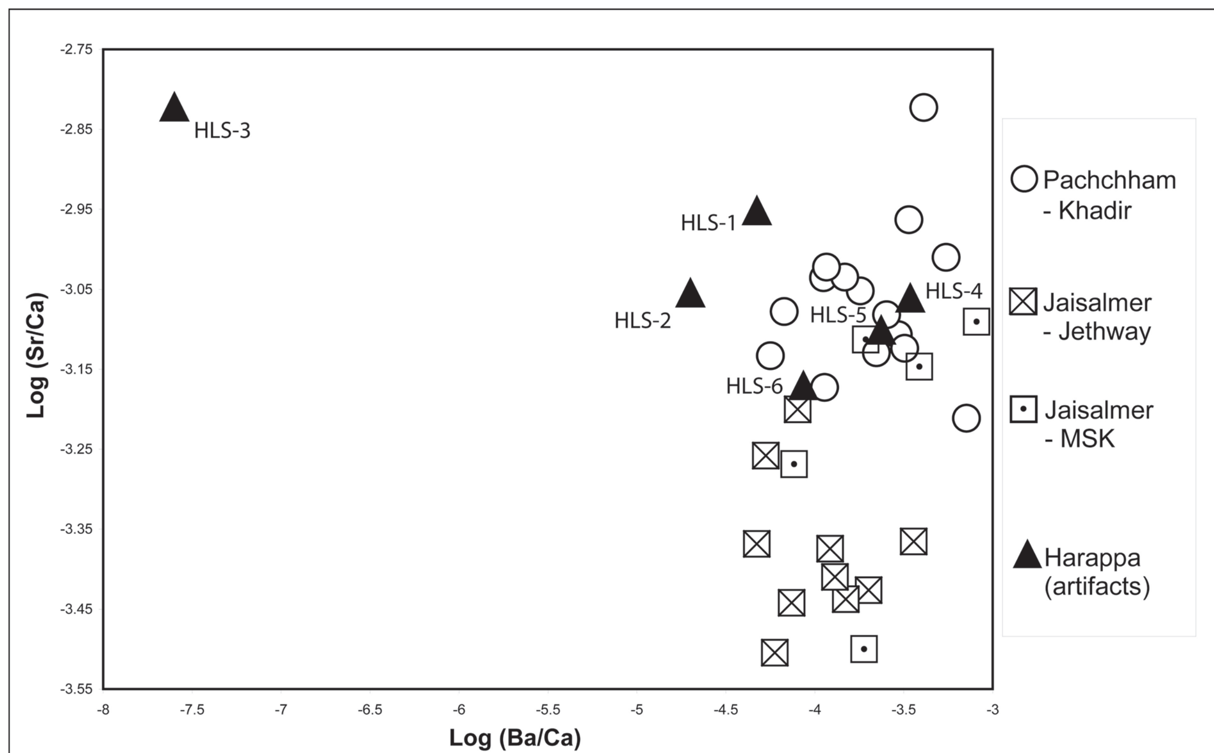



**Figure 11.26** ICP-AES analysis of the initial limestone sample set (bivariate plot).

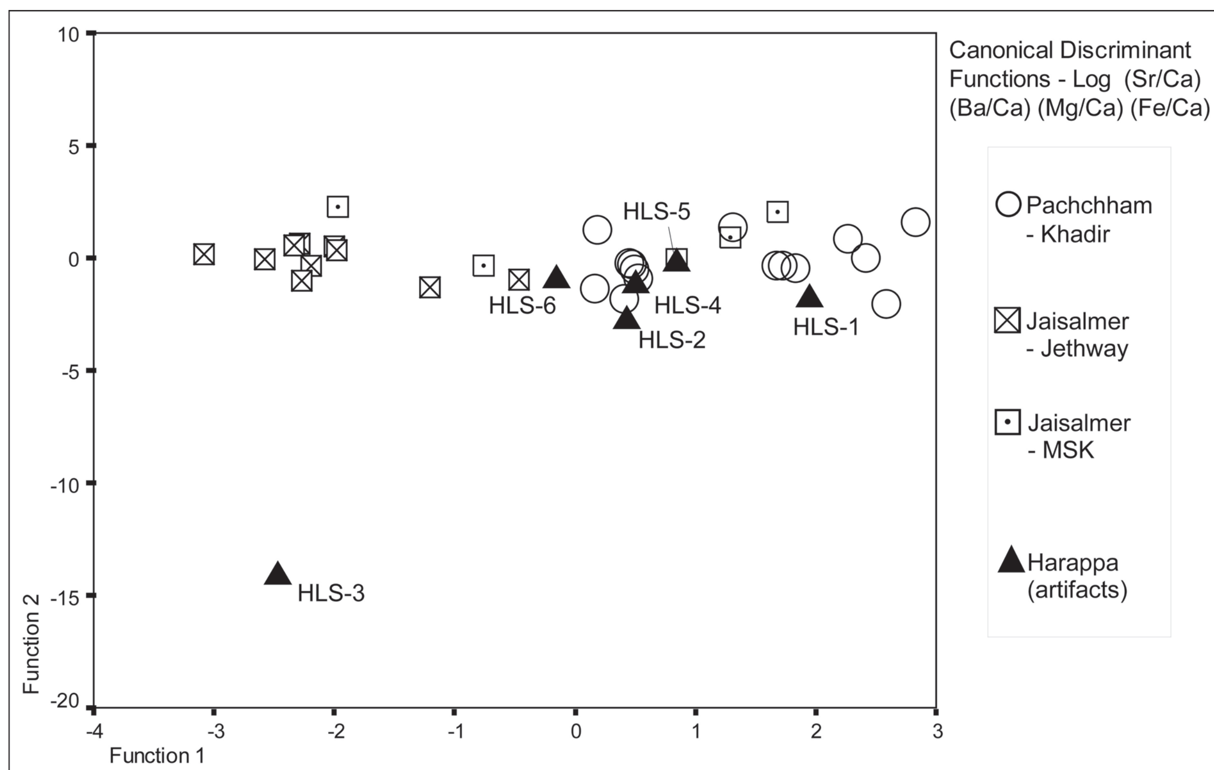



**Figure 11.27** ICP-AES analysis of the initial limestone sample set (CDA).

Samples from the three geologic sources alone are displayed in Figure 11.28 using a bivariate plot of their Ba and Sr values (divided by Ca and log normalized). Although there is a fair degree of sample overlap in some areas along the margins the geologic groups, the three sources appear to be reasonably distinct.

In Figure 11.29 the archaeological samples from Harappa are superimposed as black triangles. With

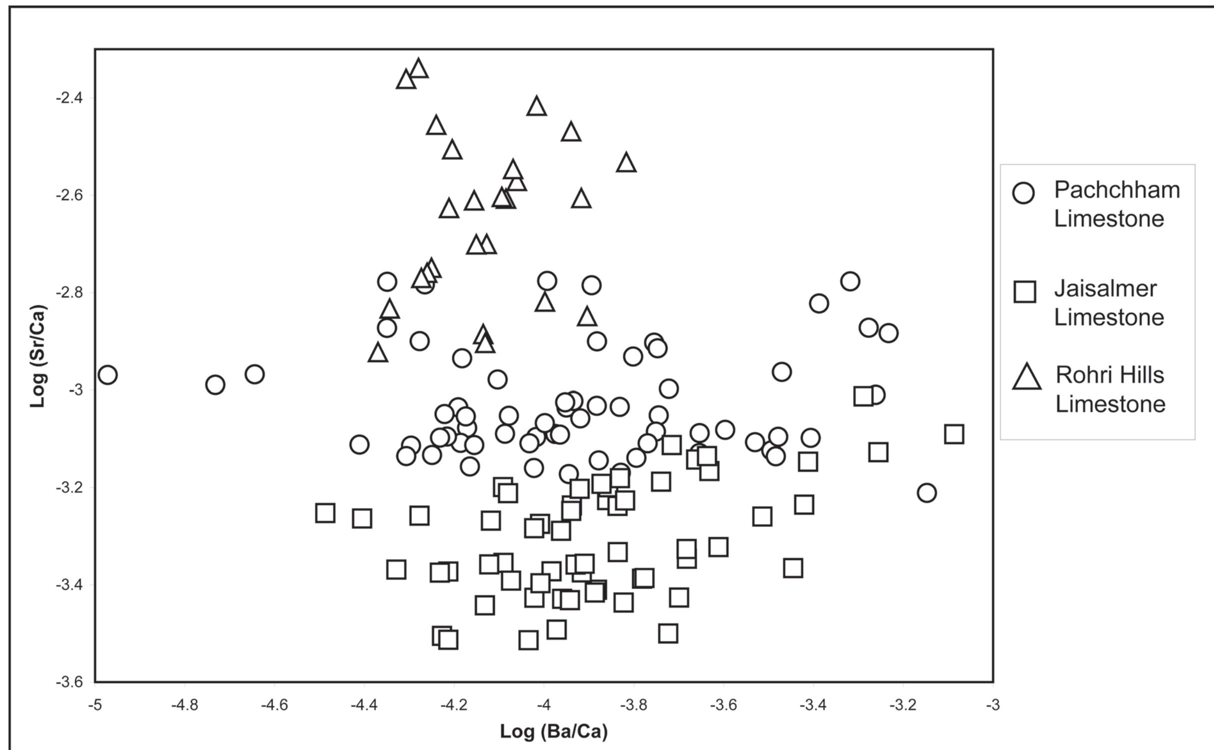



**Figure 11.28** ICP-AES analysis of expanded geologic sample set (bivariate plot).

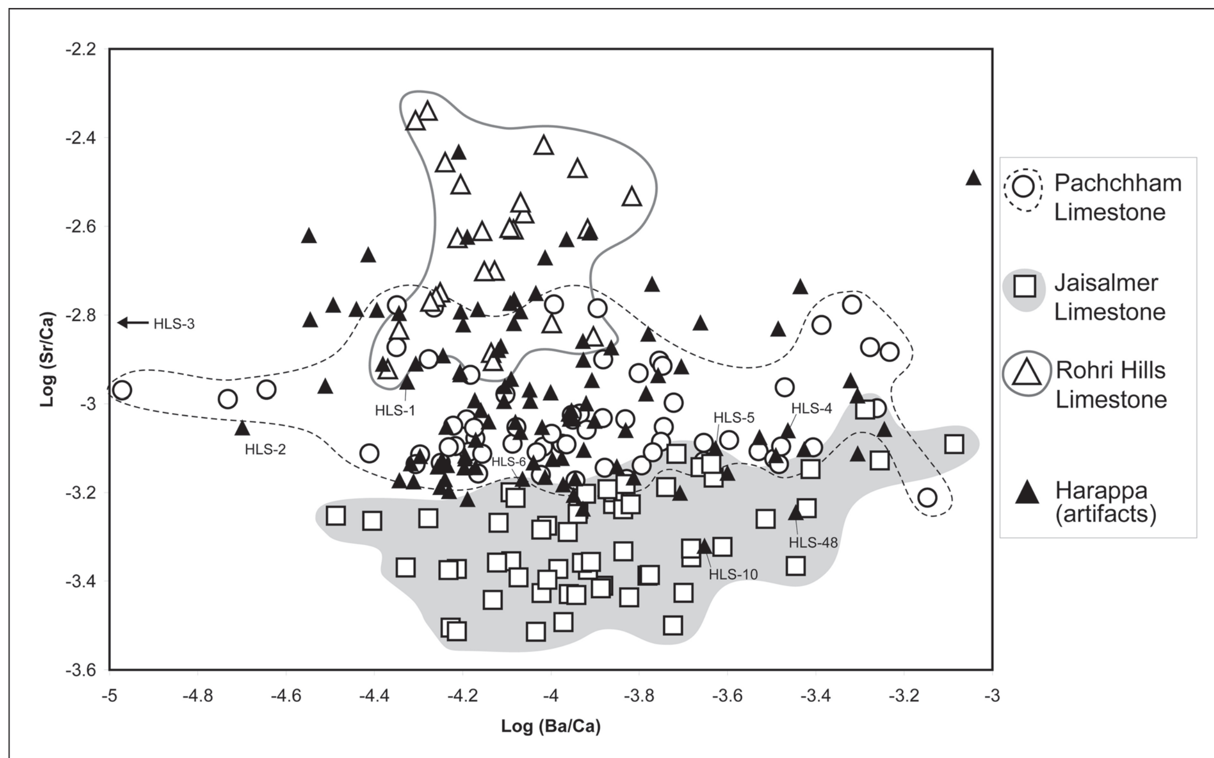



**Figure 11.29** ICP-AES analysis of expanded archaeological sample set (bivariate plot).

over 250 points now plotted the figure becomes very *busy* visually. Lines and shading have therefore been added to show the extent of the areas where geologic sources plot. Such additions, which are used frequently in upcoming figures, are only meant to be visual aids and do *not* represent confidence intervals of any kind. In this view, it is evident that the majority of archaeological samples (most of which are types

of sandy limestone) fall within the area encompassed by the Pachchham Formation. A significant number of the remaining samples plot either with the Rohri Hills group or outside of all three groups. Two artifacts (HLS-10 and HLS-48) plot squarely within the Jaisalmer group. Many samples fall in and around the area where the Pachchham and Jaisalmer groups overlap. This area is where three of the original six artifacts from the initial set consistently plotted. Those six are identified on the figure in order to provide a sense of how the expanded number of geologic samples might, or in this case might not have, helped to clarify the boundaries between the formations.

Far better separation between geologic sources is achieved when the dataset is examined using CDA (Figure 11.30). The samples from the Rohri Hills, so different in geologic age and appearance than the sandy limestone sources, form very a distinct and separate group. Although a degree of overlap is still present between the Pachchham and Jaisalmer groups, 93.3% of cross-validated geologic cases classified correctly.

When the archaeological samples are considered as ungrouped cases (Figure 11.31), the large majority once again cluster with the Pachchham group. Many samples also fall either in the Rohri Hills group or outside of all three groups. The two artifacts that had plotted in the Jaisalmer group in the bivariate plot now fall away from that group. However, the predicted group membership (based on distance to the Jaisalmer group center point as compared to the other group's center points) of those and four other samples is the Jaisalmer group.

The purpose of this first look at the expanded set was not to assign provenience to archaeological samples. The primary purpose was to determine which method of looking at the data (bivariate plotting or CDA) produced the best results. Best separation between groups was achieved using CDA and, therefore, this method is the one used for all remaining evaluations of the dataset. Another purpose was to get a general sense of how the archaeological samples grouped when compared with the expanded geologic dataset. The majority of artifacts seem to group with the Pachchham Formation. However, many of those fell in the area where that group overlapped with the Jaisalmer Formation. A significant number of others were probably unrelated to either those two groups. In order to determine the probable geologic provenience of the archaeological samples, I now begin to examine the dataset by focusing on the individual material types defined earlier in this chapter

***BANDED yellow-brown and yellow-brown sandy limestone***

Let us first examine banded yellow-brown and yellow-brown sandy limestone artifacts. The 31 examples from Harappa in this visual type category are plotted as ungrouped cases against samples from the Pachchham, Jaisalmer and Rohri Hills limestone formations (Figure 11.32). The black triangles with white circles on the figure identify samples taken directly from the two banded yellow-brown ringstones from the Harappa Museum's reserve collection (HLS-7 and HLS-8, pictured in Figure 11.4 D). At this level (in which 93% of cross-validated geologic samples classified correctly) the predicted group membership of all samples is the Pachchham Formation. Many of the artifacts do, however, cluster near the area where outliers of the Jaisalmer group overlap with the Pachchham samples.

In the next view (Figure 11.33) we examine the Pachchham and Jaisalmer formations at the level of the individual locations from where geologic samples were collected. The Rohri Hills samples have been discarded while two yellow sandy limestone fragments from the Kirthar Range of Sindh were added. The cross-validation score at this level dropped significantly (to around 62%) due to the high intra-formation overlap between sampled locations.

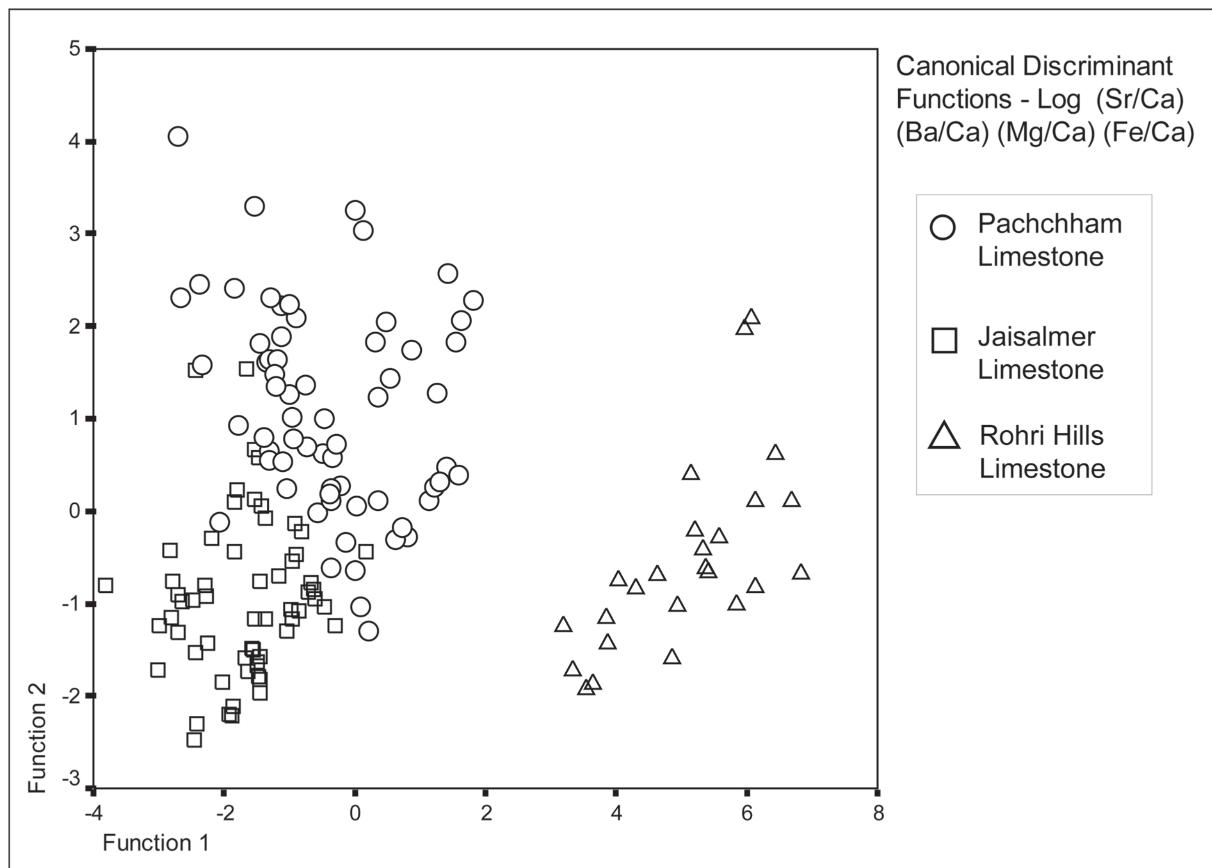



**Figure 11.30** ICP-AES analysis of expanded geologic sample set (CDA).

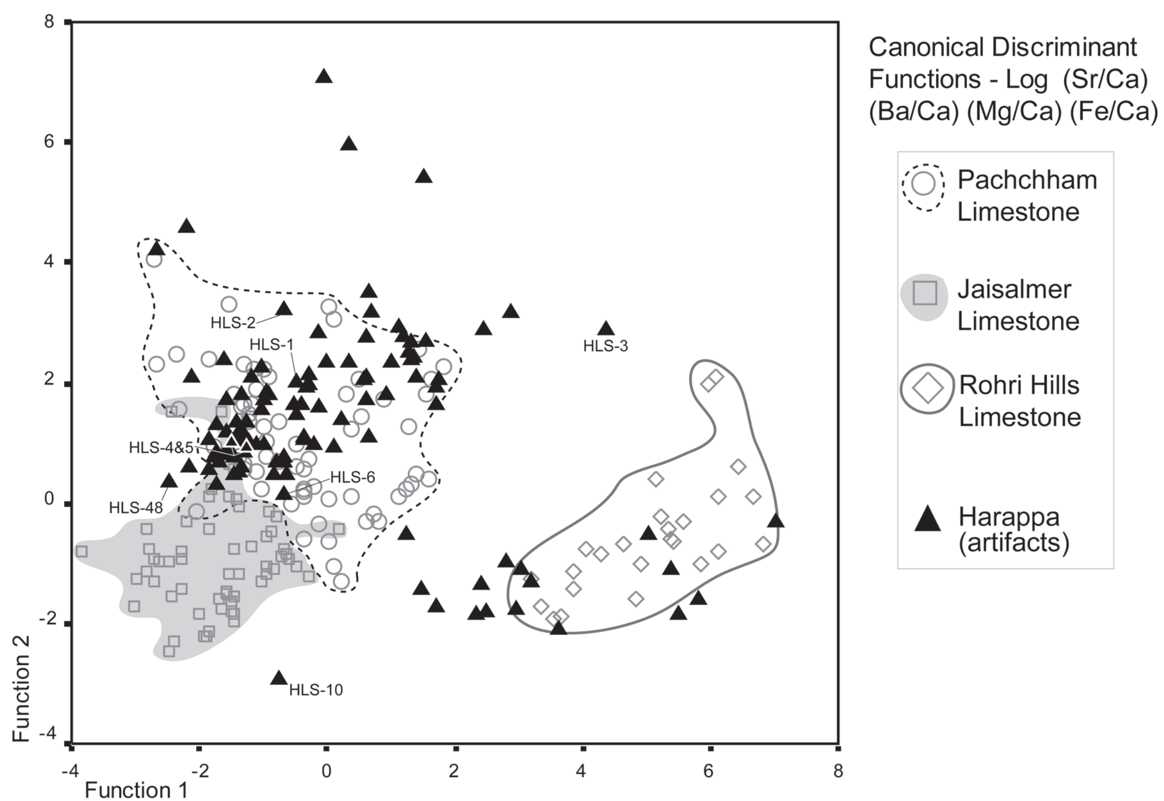



**Figure 11.31** ICP-AES analysis of expanded archaeological sample set (CDA)

Nonetheless, 28 of the 31 artifacts had a predicted group membership in the Pachchham formation. Twenty of those 28 artifacts, including the two banded ringstones, were assigned to the Khadir Island Harappan quarry group (Quarry) and the remaining eight to the Pachchham Island Juni Kuran (JK) group. Three samples, however, were predicted to belong to the Mool Sagar Khan (MSK) group of the Jaisalmer Formation. These sample points are marked with the letter "M." Note that three other artifacts group adjacent to those samples. Although predicted to belong to the Pachchham group, those may actually belong with those artifacts assigned to Mool Sagar Khan. On the other hand, all of the artifacts in this area (even the MSK ones) may simply be outliers of the Pachchham Khadir Island quarry group. When the Mool Sagar Khan, Khadir quarry and Juni Kuran sources were compared alone (not shown) only a single sample was predicted to belong the Mool Sagar Khan group.

Although the two yellow sandy limestone samples from the Kirthar Range in Sindh did plot among the Pachchham geologic group, none of the artifacts examined appeared to resemble them. However, it would be imprudent to state that Harappan yellow limestone could not have come from the Kirthar Range, especially after having only analyzed a mere two samples from that region. What is very clear is that the majority of the 31 banded yellow-brown and yellow-brown sandy limestone artifacts examined here more closely resemble Pachchham limestone than they do Jaisalmer limestone or the Kirthar samples.

***Bright or "GOLDEN" yellow-red sandy limestone (Jaisalmer stone?)***

Now we turn to the category of sandy limestone artifacts that bears a very strong resemblance to Jaisalmer stone. Twenty-two artifacts made up this sub-set of bright yellow to bright yellow-red or "golden" sandy limestones.

The 25 examples in the dataset of this macroscopic category are plotted as ungrouped cases against samples from the Pachchham, Jaisalmer and Rohri Hills limestone formations (Figure 11.34). It immediately is evident that this group and those in the previously examined banded yellow-brown sandy limestone category (Figure 11.32) plot in a very similar way. At this level, 19 of the Harappan artifacts are classified as belonging to the Pachchham Formation. Three are assigned to the Jaisalmer group.

When individual sources in the Pachchham and Jaisalmer groups are compared alone (Figure 11.35), 18 of the Harappan samples are assigned a predicted group membership with Pachchham sources on Khadir Island, Kutch (17 to the Harappan quarry and one to the nearby Limdiwali Tari area) and four are predicted to belong to the Mool Sagar Khan source in the Jaisalmer Formation (noted on the figure with an "M"). When the archaeological samples are compared to those four assigned sources alone (not shown), Mool Sagar Khan looses one member while Limdiwali Tari gains one.

These results would seem to suggest that the many of the artifacts identified as Jaisalmer stone by past excavators of Harappa (and Mohenjo-daro) may in fact have come from sources in Kutch. However, three to four of the Harappan artifacts were predicted to belong to Mool Sagar Khan in the Jaisalmer Formation and I believe that at least some of the other artifacts in this sub-set may have been incorrectly classified as coming from Pachchham sources. For example, sample HLS-044 (noted on Figure 11.35 and pictured in Figure 11.6, *bottom row center object*) is an artifact from Harappa that has the same bright yellow-red of classic Jaisalmer stone (Figure 11.3) but is predicted by CDA to belong to a Pachchham source. None of the stone that I have seen when visiting source formations in Kutch, however, have quite the same "golden" yellow hue of this or many other samples in this category – but granted, I have only visited a handful of located within that region.

Perhaps the possibility that some artifacts

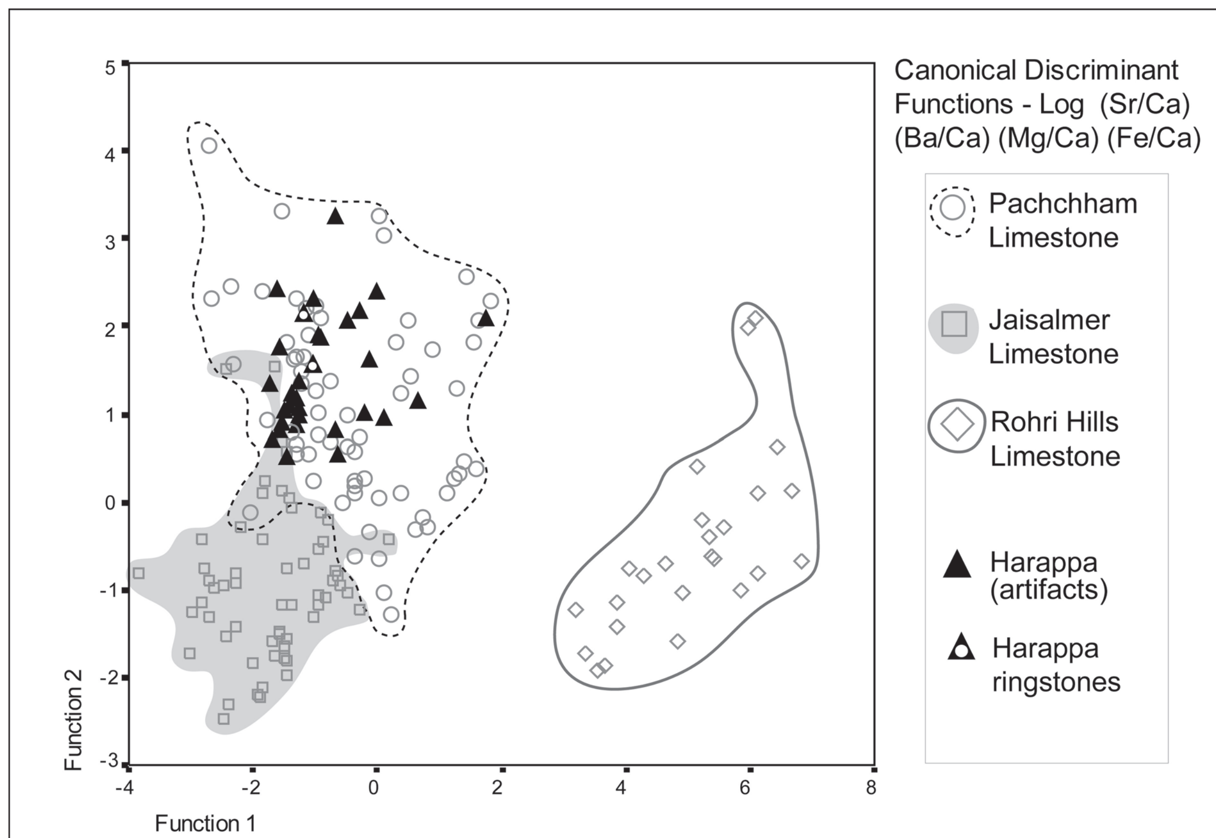



**Figure 11.32** ICP-AES analysis of BANDED yellow-brown limestone artifacts (CDA).

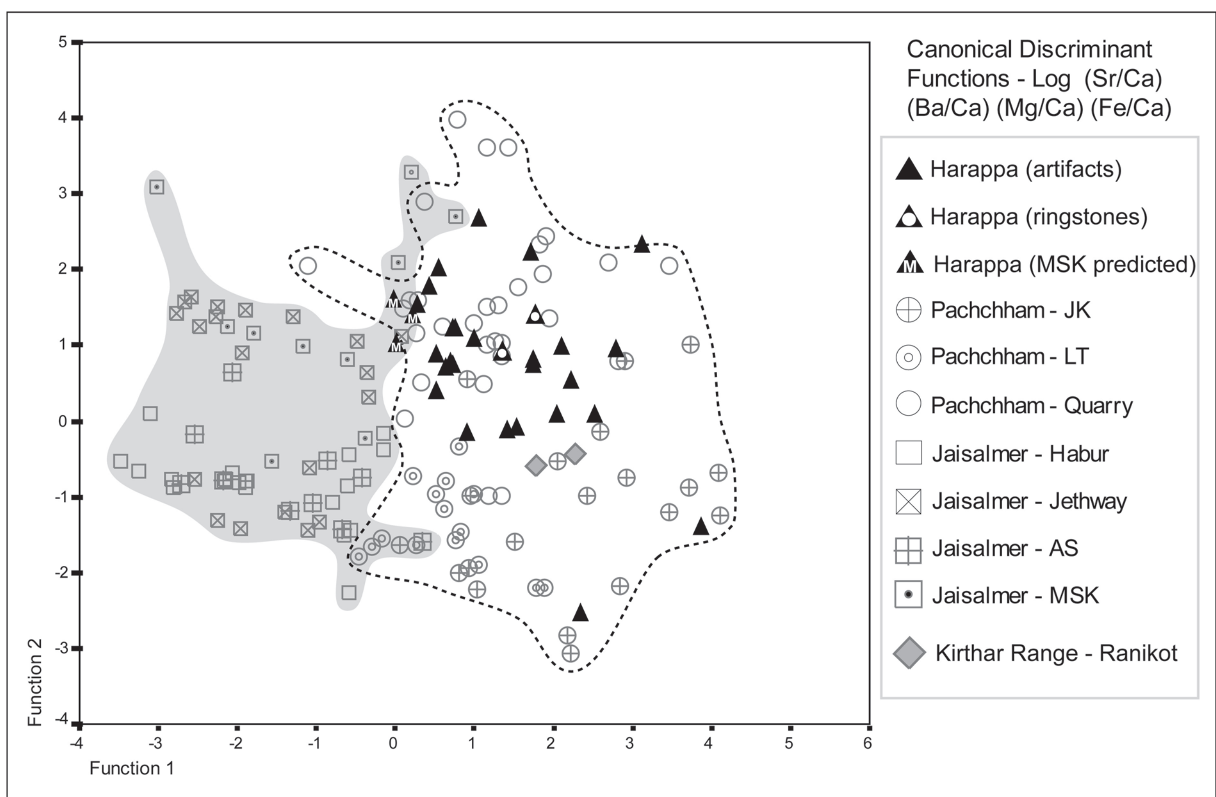



**Figure 11.33** ICP-AES analysis of BANDED yellow-brown limestone artifacts vs. select geologic sources (CDA).

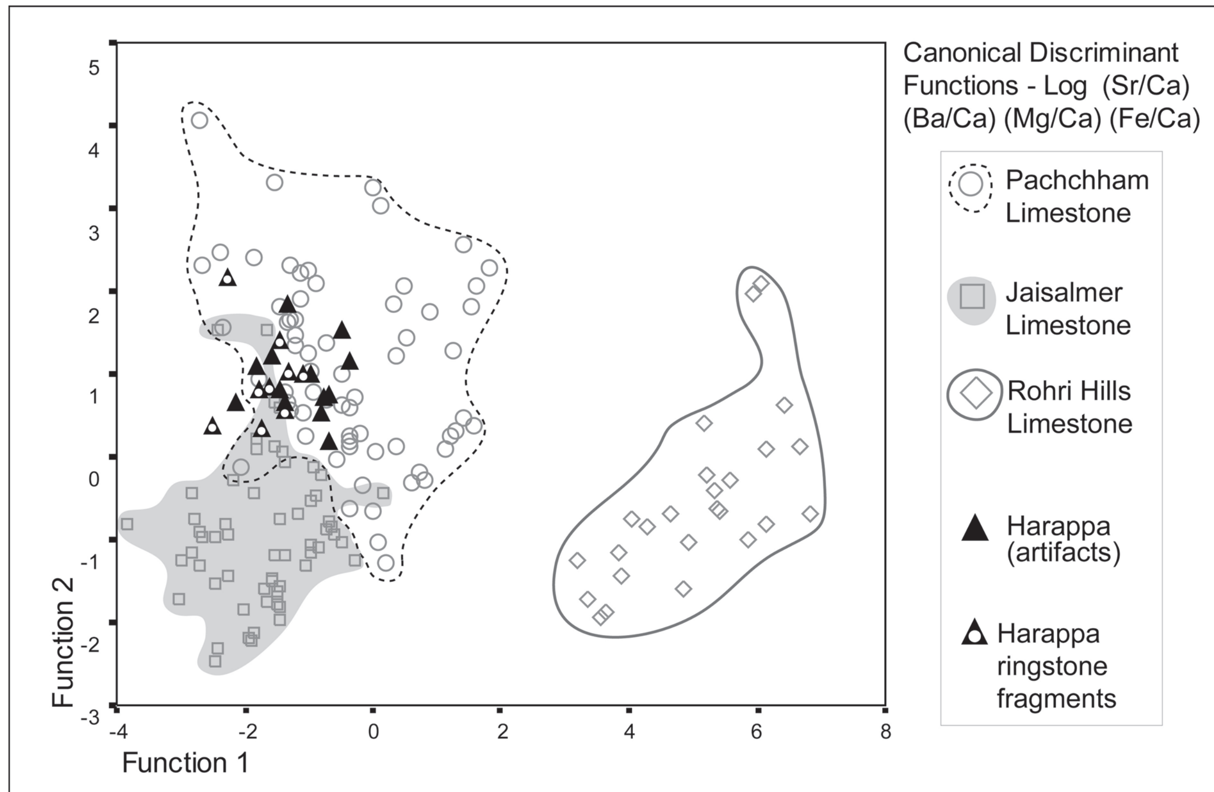



**Figure 11.34** ICP-AES analysis of yellow-red "GOLDEN" sandy limestone artifacts (CDA).

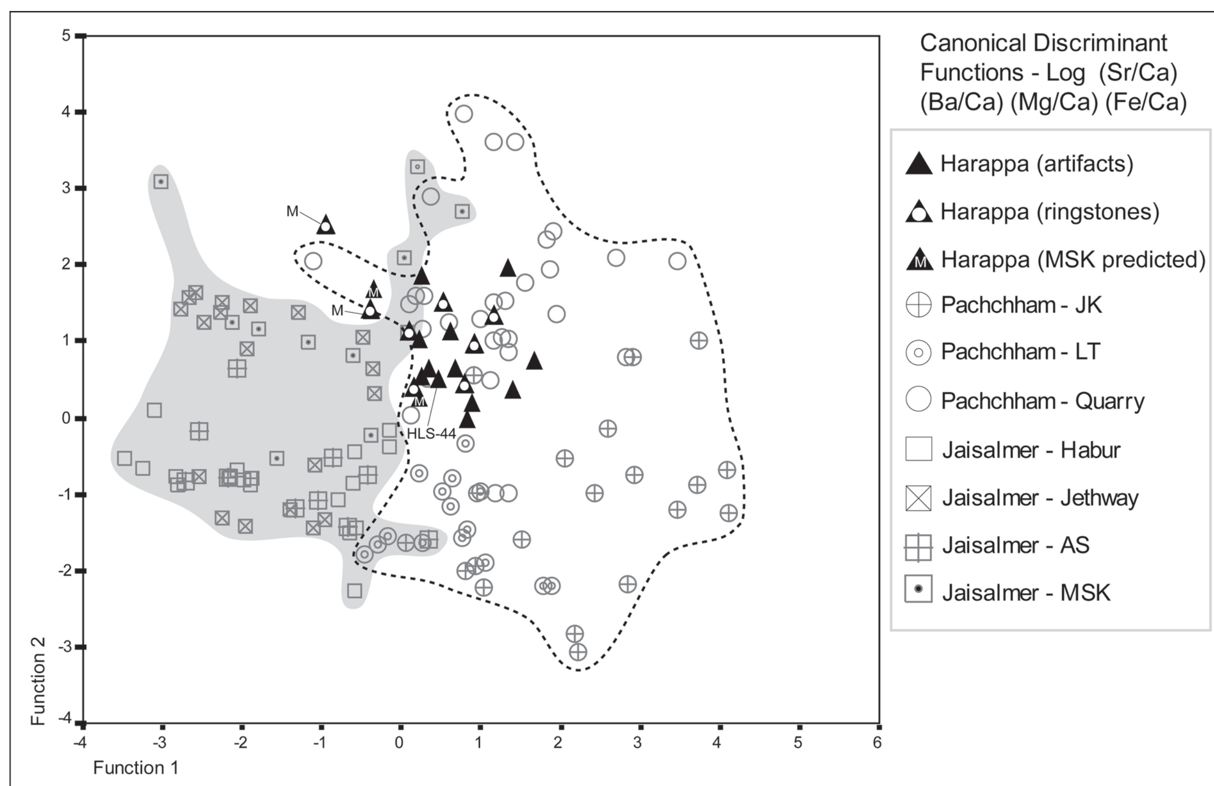



**Figure 11.35** ICP-AES analysis of yellow-red "GOLDEN" sandy limestone artifacts vs. select geologic sources (CDA).

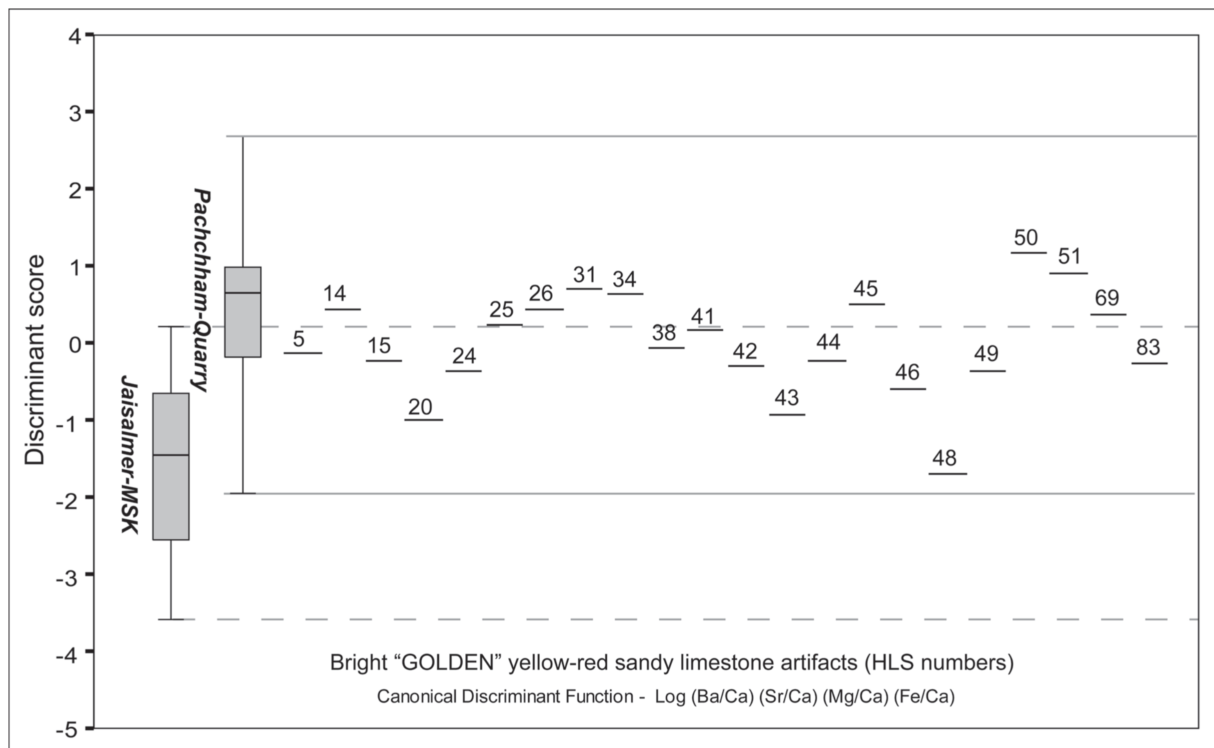



**Figure 11.36** Box plot comparison of Pachchham quarry vs. Mool Sagar Khan geologic sources and "GOLDEN" limestones artifacts based on discriminant scores.

*may* have been misclassified using CDA can be best illustrated by comparing the two overlapping sources alone. Figure 11.36 is a box plot (recall how this was previously used in Chapter 8 to compare agate artifacts to geologic samples from two sources – Figure 8.35) based on the discriminant scores generated when the Mool Sagar Khan (Jaisalmer) and the Khadir Island quarry (Pachchham) were compared alone and the bright yellow-red limestone artifacts were considered ungrouped. I have added horizontal lines indicating where the furthermost outliers of both geologic sources are. Dashed gray lines indicate Mool Sagar Khan and solid ones indicate the Khadir quarry. Artifacts are plotted individually and labeled. The box plots clearly show that a significant amount of overlap exists between the two sources (80% of cross-validated cases were correctly classified) and that all of the archaeological samples plot within the area encompassed by the Pachchham limestone quarry on Khadir. However, 15 of the 25 also plot below the Mool Sagar Khan outlier with the highest discriminant score (marked with the top-most dashed line) and so could *potentially* belong to that group. HLS-044 is among those that plot in this way. Based on this fact and the artifact's appearance I am inclined to re-classify it as Jaisalmer stone. In the fifth column of Appendix 11.5 the probable proveniences of archaeological samples are listed. I have marked the original source assessment of that sample (Pachchham Formation – Khadir quarry) and other artifacts similar to it with the notation "*possibly MSK."

### *GRAY-red sandy limestone*

The final macroscopic category of sandy limestones to be considered is the gray to gray-red type. Among the 33 artifacts in this sub-set are fragments of three large gray ringstones (two of these are pictured in Figure 11.12), many architectural elements and the shoulder/haunch piece of the large bull sculpture/frieze (Figure 11.7) from Mound AB.

When the 33 gray-red sandy limestone artifacts are plotted against the Pachchham, Jaisalmer and

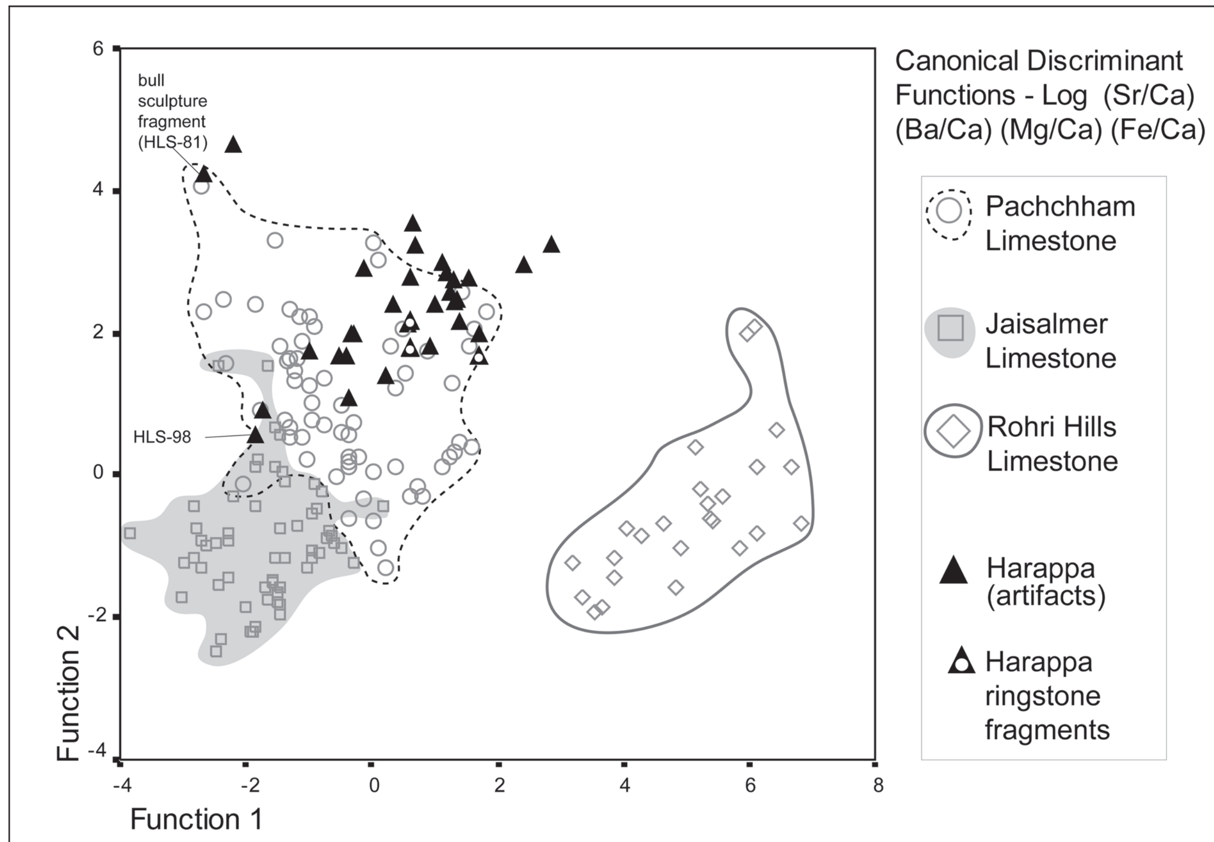



**Figure 11.37** ICP-AES analysis of GRAY and red sandy limestone artifacts (CDA).

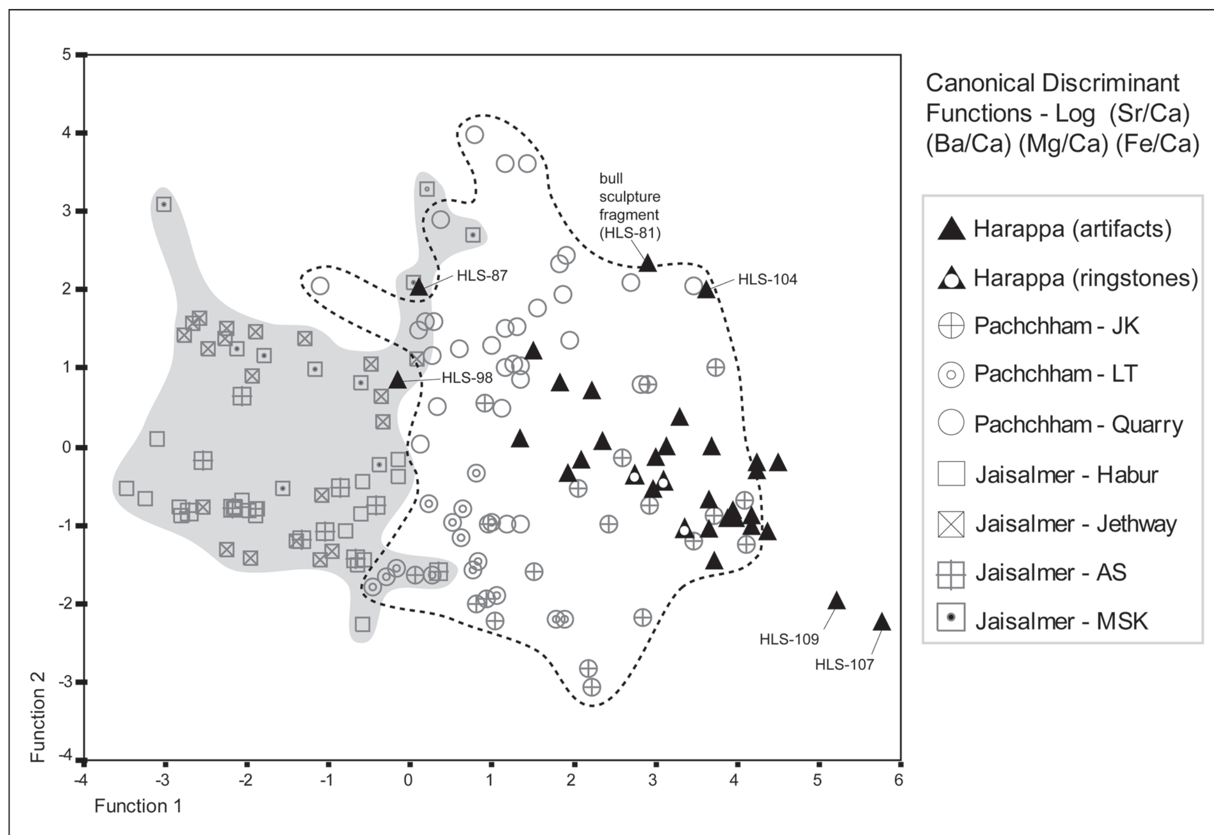



**Figure 11.38** ICP-AES analysis of GRAY and red sandy limestone artifacts vs. select geologic sources (CDA).

Rohri Hills formations (Figure 11.37) we see that, like the previous two sub-sets, the majority cluster within Pachchham group. Unlike the previous sub-sets, however, most of these plot well away from the area where the Pachchham and Jaisalmer groups overlap. At this level of analysis the predicted group membership for 32 of artifacts is the Pachchham Formation. Only HLS-98 was assigned to the Jaisalmer group.

Next the individual sources comprising the Pachchham and Jaisalmer groups are compared alone and the archaeological samples are plotted as ungrouped cases (Figure 11.38). It is even more evident now that artifacts of this macroscopic type plot differently overall than the banded yellow-brown and bright yellow-red types. Twenty-five of the 33 samples are predicted to belong to the Juni Kuran group, which is where the gray type of Pachchham limestone is best developed. The three large fragments from the gray wavy ringstones plot squarely in the center of that group. Seven artifacts are closer to the centroid of Khadir quarry group and therefore assigned to it. Some of those, however, samples may be outliers belonging to the Juni Kuran group. More distant outliers (noted on the figure with their HLS numbers) may be from a different sources altogether. One of these outliers is the sample taken from bull sculpture. It appears quite distinct from most of the other samples in thee sub-set. HLS-98 is once again assigned to the Jaisalmer Formation at Mool Saga Khan. This particular artifact is more reddish brown than gray and could conceivably have been carved from a large red patch in a piece of Jaisalmer stone.

***Micritic limestone***

Micritic limestones are found in numerous locations around the Greater Indus region. For this study, only 25 samples from one source formation, the Rohri Hills of central Sindh, were available with which to compare to the 13 micritic limestone artifacts in the sample set. The majority (n=16) of the micritic limestone samples from the Rohri Hills come from the outcrop directly adjacent to the Early Harappan and Harappan Period site of Kot Diji (Khan 1965). The remaining nine samples are from various outcrops extending from Rohri town in the north to Kandarki in the south (these locations are discussed in greater detail in the Rohri Chert section of Chapter 6). Although having samples from micritic sources in other regions would be preferable, useful information can nonetheless be gained by determining how similar or dissimilar the Harappan micritic limestone artifacts are to samples from the Rohri Hills.

We see that the 13 micritic limestone artifacts from Harappa spread widely when plotted as ungrouped cases against the Pachchham, Jaisalmer and Rohri Hills formations (Figure 11.39). A handful of artifacts fall in or near the Rohri Hills group but the rest, including a large block that may have been a drain cover and the single micritic sample in the initial archaeological set (HLS-3), seem to be unlike limestone from that formation. This would suggest that multiple sources of micritic limestone were used by residents of Harappa.

How similar or dissimilar the Harappan artifacts are to Rohri Hills limestone becomes even more evident when the other formations are discarded and the various sources within the Rohri Hills group are considered alone (Figure 11.40). Again the drain cover (HLS-3) and several other samples plot away from the Rohri Hills group. Seven artifacts, however, do closely cluster with the geologic samples. Until samples from other micritic sources can be analyzed I provisionally suggest that Harappans acquired this type of limestone from multiple sources, one of which was likely the Rohri Hills of Sindh

***WHITE chalky porcelaneous limestone***

White chalky porcelaneous limestone is the final type of material in the archaeological set and are now briefly examined. This sub-set of consists of samples taken from six non-descript fragments and

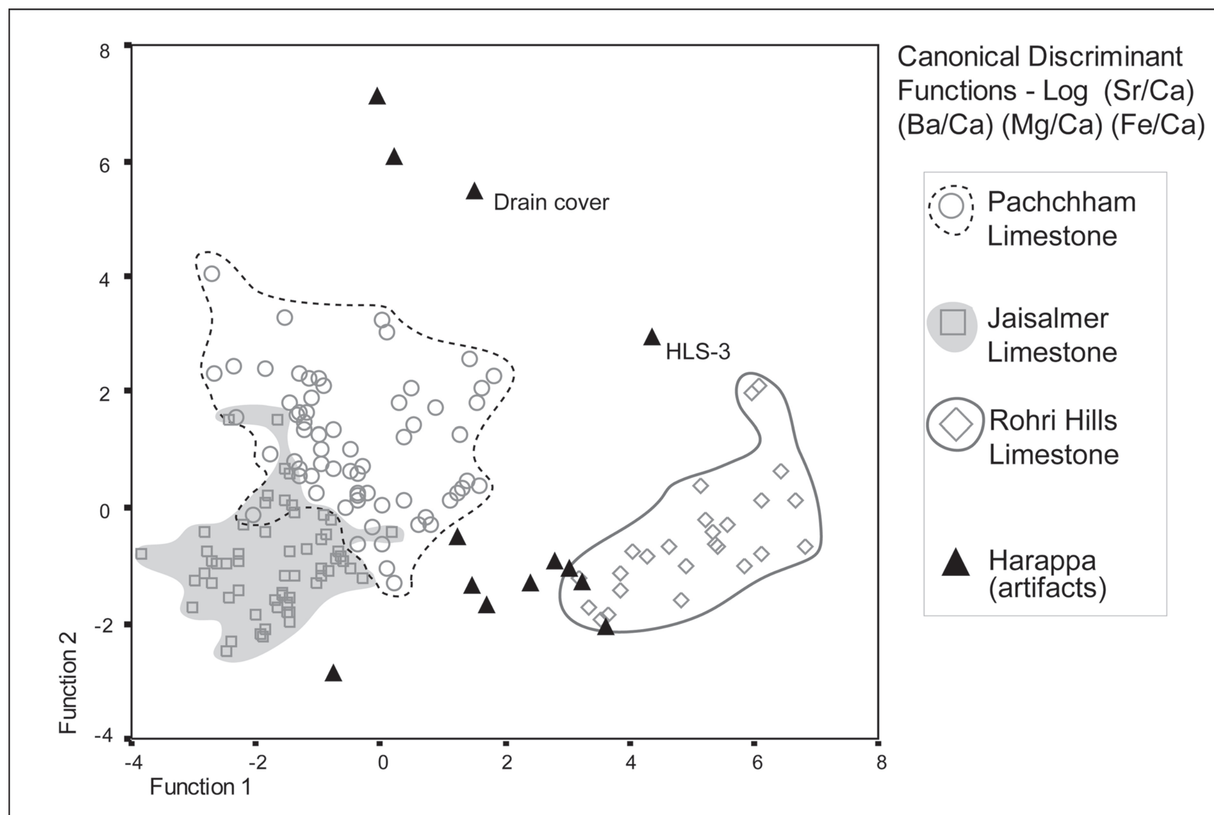



**Figure 11.39** ICP-AES analysis of microcrystalline (MICRITIC) limestone artifacts (CDA).

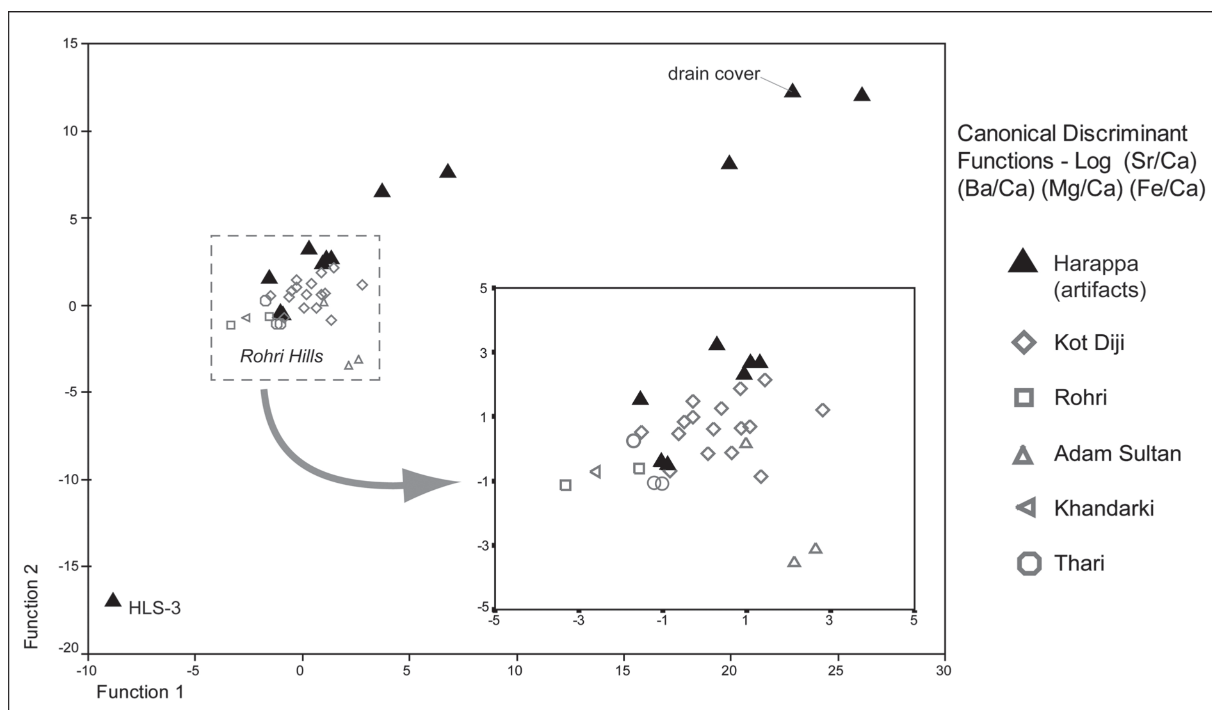



**Figure 11.40** ICP-AES analysis of microcrystalline (MICRITIC) limestone artifacts vs. Rohri Hills sources (CDA).

two from a pair of large conical objects. The cones are pictured in Figure 11.4 and are likely same the two reported by Vats (1940: 51) as coming from Trenches III and IV. Although none of the limestones from the three main geologic sources examined in this study much resembles the artifacts, a eight samples from two sources of white limestone have been added to supplement the geologic set. Three of the

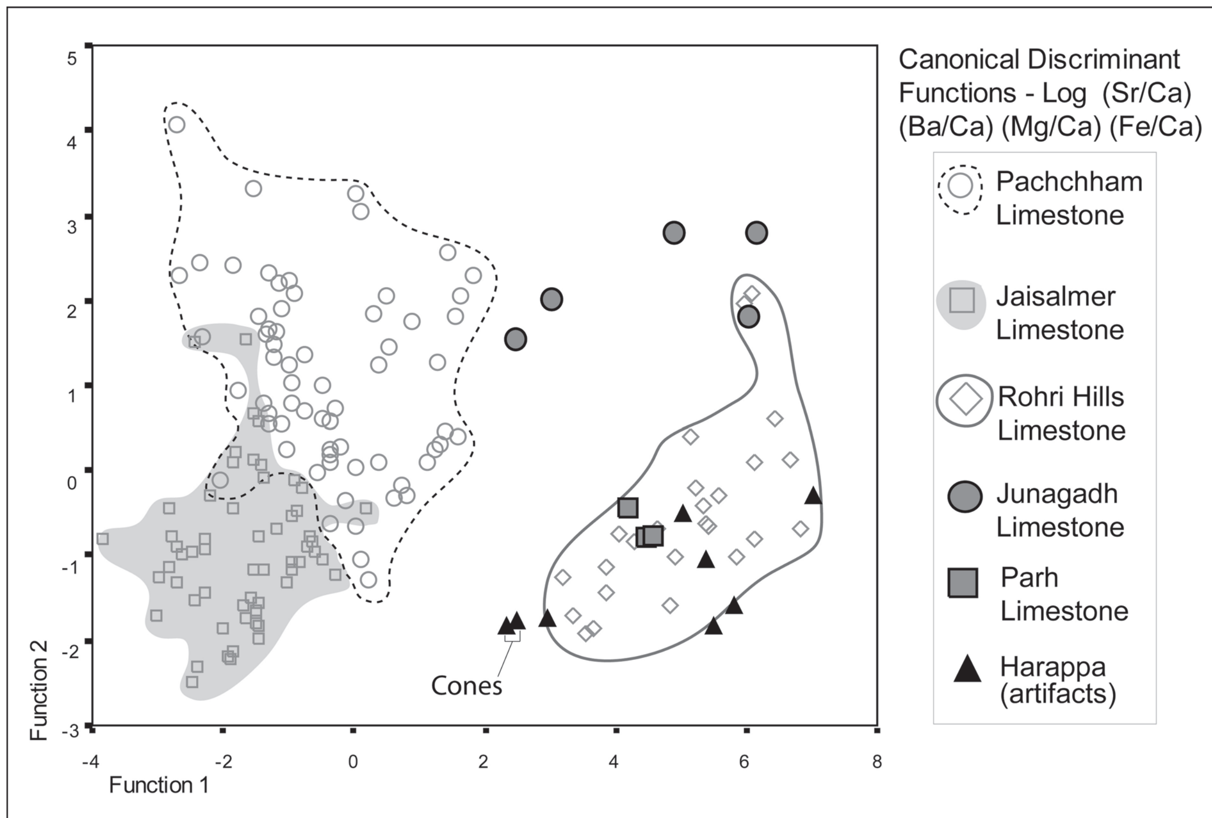



**Figure 11.41** ICP-AES analysis of WHITE porcelaneous limestone cones and fragments (CDA).

additional geologic samples are white porcelaneous Parh limestone (pictured in Figure 11.21) collected near the site of Dabar Kot (Fairservis 1959) in the Loralai District, northern Balochistan. Five others are a soft chalky white limestone from Adityana in the Junagadh Distinct of Saurashtra (Desai and Pathole 1979). Although the latter tends to be a much softer material than the white limestone from Harappa, I have included it in this analysis in order to provide another group for comparison.

When plotted against the geologic samples we see that the eight white limestone artifacts cluster in or near the Rohri Hills group (Figure 11.41). Although I have not seen or heard of any chalky white limestone in the Rohri Hills, this is not to say it could not occur at some point along its approximately 80 km length. Interestingly, the three Parh limestone samples plot within the Rohri Hills group and a couple of the Harappan artifacts fall near them. Parh limestone is "exposed extensively in the Kirthar-Sulaiman region" (Kazmi and Jan 1997: 95). It is possible then that the white limestone artifacts may derive from one of these regions west and southwest of Harappa. The samples from the two cones plot very close to one another confirming that were probably made from the same stone, probably at the same time. They are quite distinct from both the chalky white limestone from Adityana, Gujarat and the Parh limestone samples from Loralai, Balochistan.

***Section summary***

Good separation overall between the geologic sources of sandy limestone (Pachchham and Jaisalmer) was achieved using CDA on ICP-AES derived data, although there was a degree of overlap between the two. When compared as ungrouped cases, many of the archaeological samples fell in and around the area of overlap. Most of the three types of sandy limestone artifacts from Harappa were predicted to belong to sources within the Pachchham formation of Kutch. Some samples of each of the types, however, did fall close enough to geologic groups in the Jaisalmer

formation of western Rajasthan to be assigned that provenience. Those that did so may simply be outliers of Pachchham limestone. Or they may actually come from Jaisalmer sources, along with many other artifacts that plotted in or near the area of overlap and were assigned to Pachchham sources. Those bright yellow-red sandy limestones artifacts that that fell within the range of variation for the Mool Sagar Khan source and *look* like Jaisalmer stone, very probably are Jaisalmer stone. So in the end the provenience determination made by past and present excavators based on the appearance of those artifacts was likely correct in most cases.

Most of the banded yellow-brown sandy limestone artifacts analyzed were clearly analogous to Pachchham limestone. The majority (especially the two large ringstones) grouped closely with samples taken from the Harappan period quarry near Dholavira. Similarly the gray-red sandy limestone artifacts largely corresponded with the Pachchham limestone deposits of Pachchham Island – an area that is notable for the gray type that occur there. It is always possible that sources of limestone resembling these types will be identified elsewhere or that fuller characterization of the Jaisalmer Formation may eventually result in the need to reclassify the provenience of those artifacts. The same may be the case when a larger set of samples from the Kirthar Range are eventually analyzed. However, at this time, the results strongly suggest that most examples of these sandy limestones used for large objects at Harappa derived from sources 800 km away in Kutch.

The analysis of micritic limestones in the sample set indicated that materials from multiple sources (three or more) were brought to Harappa. This is not particularly surprising as micritic limestone formations practically line the Indus Basin (particularly on its northern and western margins). A group of the Harappan artifacts appeared to be very similar to geologic samples analyzed from Rohri Hills of Sindh indicating that source *may* have been one of the ones used. However, as no other geologic sources of micritic limestone were available for comparison that conclusion should be considered tentative.

The series of chalky white porcelaneous limestone artifacts analyzed were most geochemically analogous to samples from the Rohri Hills of Sindh, although no occurrences of that type of limestone has been reported from that formation. Three samples of white Parh limestone from Balochistan were analyzed and did appear somewhat like several of the Harappan samples. Although white limestone artifacts at Harappa most probably did come from Balochistan, much more work remains to be done before they can be assigned to any particular formation.

## DISCUSSION: LARGE LIMESTONE OBJECTS AT HARAPPA IN CONTEXT

Indus craftspeople used limestone to create many different kinds of objects. Some of the limestone artifacts excavated at Harappa are small in size – cubical weights, beads, inlays, discs, balls and mace heads. The great majority, however, are either bulk stone objects (as defined in Chapter 1), broken pieces that were clearly a part of such objects at one time or non-descript flakes and chunks. The flakes and chunks themselves tend to be comparatively big in size (e.g. bigger than is typical of other kinds of stone debris) and may represent waste produced during the manufacture of bulk-sized limestone objects. Or they might simply be non-diagnostic pieces broken off of already finished items of that kind. Whichever the case may be, after grindingstones (Chapter 5), most of the artifacts in Harappa's rock and mineral assemblage that fall into the bulk size/weight category are composed of one of the types of limestone discussed and analyzed in this chapter. As I have shown, several of these types seem to have been obtained from sources as far away as Kutch. In this final section, I

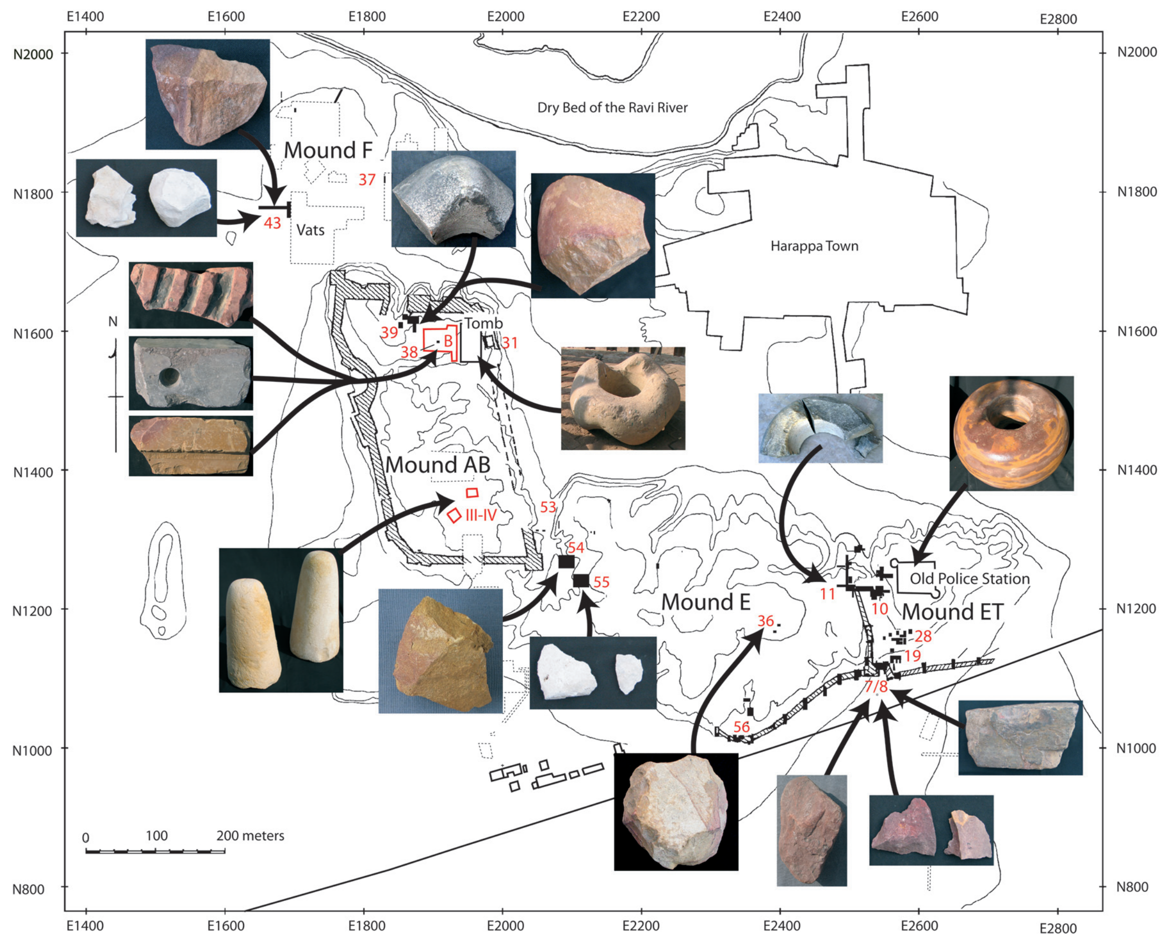



**Figure 11.42** Trenches from which the limestone artifacts analyzed in this chapter came and select artifacts representing the distribution of the different macroscopic types.

discuss the spatial and temporal contexts that large limestone artifacts appear in at Harappa, as well as the possibility that their use may have represented a new form of social expression for certain groups of Indus Civilization peoples.

The 107 seven limestone samples analyzed for this study represent a little over one-third of the total assemblage for this material variety. The excavation trenches that those samples came from are marked in red on Figure 11.42. During the period of time that limestone was used most intensively at Harappa (Period 3C – discussed below) it is found on every mound at the site. The photographs on the figure are intended to selectively illustrate how the five main types of limestone do not appear to have been restricted to one area or another. For examples, the relatively abundant type yellow banded sandy limestone is found on multiple mounds. Although there is an especially heavy concentration of limestone artifacts on the northeast corner of Mound AB (Trench 39 and Sahni's Trench B), by and large, all types of this material were available to people in most parts of the site.

All of the limestone objects analyzed for this study came from either Period 3C deposits or unstratified/disturbed contexts that are most likely representative of Period 3C or later phases. In fact, finds of limestone artifacts of any kind in levels earlier than that are comparatively rare. None are found in the Ravi Phase. A handful of brownish micritic-textured limestone artifacts, including the earliest cubical weight (Meadow and Kenoyer 2001: 26), come from Period 2 levels on Mound AB. The material is absent once again from the rock and mineral

assemblage during Period 3A. A dozen fragments, a cubical weight and an inlay of some kind have been recovered from 3B levels in various parts of mounds E and ET. The 250 or so objects making up the remaining portion Harappa's limestone assemblage are mostly large in size and come from deposits that date to Period 3C or later. A group of ringstone fragments and some of the blocks that may be architectural elements were found filling a depression in front of a doorway in Trench 39 together with pointed-base goblets, an association which firmly dates them to Period 3C (Meadow *et al.* 1998: 6). Although large limestone artifacts have been recovered in these levels across Harappa, it would probably be inaccurate to think of them as being common at that time – at least not in the sense that every Harappan home had a facade of carved limestone blocks or ringstones adorning their entryways. Rather, items made of this stone were likely used to a limited degree for special buildings or in important areas of the site.

Although it is difficult to say precisely where in Harappa's chronological sequence limestone artifacts from past excavations should be placed, most appear to have come from the site's later levels. For example, when excavating the "Granary" area on Mound F, Vats noted that a Jaisalmer stone mace-head recovered there appeared "to have found its way down from an upper stratum" (Vats 1940: 22). The association of the large limestone objects from Sahni's excavations on the northeast corner of Mound AB with pointed-base goblets definitely dates them to around Period 3C (Vats 1940: 139). Interestingly, at Mohenjo-daro the utilization of limestone for large objects also seems to have been mostly restricted to that site's "Late Period", a time roughly equivalent to the latter part of the urban phase at Harappa. A cache of 18 large limestone ringstones was found in a Late Period side chamber of House V in the HR area (Sahni 1931a: 191) and several more were recovered in the same levels in Area L (Mackay 1931b: 174). Marshall noted that the limestone blocks from the Rohri Hills used for drain covers at Mohenjo-daro, did "not seem to have been introduced before the Late Period" (Marshall 1931c: 31). Even a series of comparatively large stone statues, several of which were made of limestone, came from the later levels at that site (Ardeleanu-Jansen 1984, 1991). It would therefore appear that during the latter part of the Indus Civilization's urban phase (ca. Period 3C at Harappa), limestone began to be utilized at the two largest Indus cities a great deal more than it had been in previous times, especially to create objects that were of larger size than Harappans typical made up to that point. The question then arises – why at that time and not before?

The increased use of limestone at Harappa in the late urban phase cannot be explained by new found access at that time to the source regions examined in this chapter (except *perhaps* Jaisalmer). Evidence presented elsewhere in this book demonstrates that rock and mineral resources were being brought to the site from Gujarat (agate-carnelian), Sindh (chert) and Balochistan (lead) prior Period 3C. Advancements in the ability to transport stone in bulk sizes long distances do not provide a suitable explanation either. Carts capable of handling heavy loads appear to have existed since the Early Harappan Phase (Kenoyer 2004). The use of watercraft to move heavy loads long distances is implied by the finds of large Harappan black-slipped jars (made at cities like Harappa and Mohenjo-daro and capable of holding 30 to 40 liters of oil, wine or some other substance) at sites across the Arabian Sea in Oman (Méry and Blackman 1999).

Rather than changes in source access or transportation technologies, the evident shift at Harappa (and possibly Mohenjo-daro) in limestone utilization likely had more to do with the nature of this particular material variety in combination with the preferences of those who would use it. Although limestone was widely available across northwestern South Asia, it probably was not used a great deal prior to the late urban phase simply because, for the most part, it was a material that did not suit the

needs of Indus craftspeople or the wants of consumers during earlier periods. Harappans could have easily used it for grindingstones but sandstone-quartzites and igneous rocks were available and are much superior materials for that purpose. Limestone was sometimes used to make cubical stone weights but harder rocks like chert were clearly preferred (≈ 80% of such weights at Harappa are chert – only ≈ 5% are limestone). The reason it was so seldom used to create personal ornaments or other small items probably was because Harappans had access to rocks that were much more durable and/or aesthetically pleasing to them.

On the other hand, limestone is an excellent material to use when making large objects. It tends to break with a conchoidal fracture and is softer than sandstone, quartzite or igneous rocks such as granite or diorite. Thus, objects like ringstones are more easily roughed out and carved from limestone. At the point in time when Harappans began to feel the need to create larger objects out of stone, it was a natural material for them to choose. Huge formations of limestone were accessible within a distance of 250 km from Harappa in Sulaiman Range and Salt Range and they may very well have used some of the micritic types from those sources. Certain types, although found in more distant locations, were clearly desired for their aesthetic properties just as they are today (e.g. Jaisalmer stone). That different types of limestone from multiple sources were used at Harappa and that some of those sources were quite far from the site simply reflects the great extent of rock and mineral exchange networks in place during Period 3C.

However, the question remains – why, especially if sources were readily accessible and the technologies needed to move heavy stone had long existed, was it not until the latter part of the urban phase (ca. 2200-1900 BC) that large limestone objects began to appear at sites like Harappa and Mohenjo-daro? I believe that this phenomenon probably reflects a new development in the way Harappans (or at least certain Harappans) expressed social power through the consumption and display of stone. Until that point, the creation of small, high-value personal ornaments that signaled the status of those wearing them was one of the principal means through which social and economic hierarchy in the Indus Civilization was marked and maintained (Kenoyer 2000). The wealth-status value of such ornaments is argued to have been largely dependent on two factors – the relative scarcity of the raw materials being used and the level of technological complexity/virtuosity needed to turn them into finished items (Kenoyer 1992a: 45; Vidale and Miller 2000). With bulk stone objects *size* becomes a relevant third factor. A single ringstone weighing 100 kg would have required as much effort, energy and/or expense to bring to Harappa from Kutch as would 100 kg of high quality carnelian nodules. The difference is that with the nodules hundreds, perhaps thousands, of carnelian beads could have been created and dispersed while with a ringstone all of the effort-energy-expense was concentrated within a single item. Bulk stone objects of this kind thus would have probably been important symbols of wealth, prestige and power for Indus Civilization peoples living at settlements located upon the alluvial plains. Their display may have also been a visible marker of a social or territorial relationship held with the distant region where the stone originated. Using such stones in the construction or adornment of religious spaces, private buildings or public areas such as gateways or streets would have been a powerful expression of a person's, a social group's or an organization's ability to expend energy, wealth or influence (probably all three). The timing of the emergence of this new behavior at Harappa and Mohenjo-daro is interesting as it roughly coincides with other changes seen at those cities during the latter parts of their urban phases such as the widespread use of pointed-base goblets and fluctuations in civic control evident as periods of degrading architecture and poor maintenance of

public thoroughfares (Dales 1979: 193-194; Kenoyer 1993: 186-187).

## CHAPTER CONCLUSION

The acquisition and use during Period 3C at Harappa of expensive-to-transport large limestone objects from multiple sources, some as far away at Kutch, represented a new way for Indus Civilization people living there to express prestige and power using stone. In the following chapter, I attempt to identify the geologic sources of various metals – a category of material the use of which may also have been, at times, prestige-related.

# CHAPTER 12

# LEAD, SILVER AND COPPER ACQUISITION NETWORKS

## CHAPTER INTRODUCTION: METALS

Of the many rock and mineral varieties found at Indus Civilization sites, archaeologists have by far expended the most time and effort in the study of artifacts made of metals, in particular copper (for recent overviews see Agrawal 2000; Agrawal and Kharakwal 2003; Biwas 1996; Chakrabarti and Lahiri 1996; Kenoyer and Miller 1999; Shrivastava 2006). Despite all of the attention, attempts to correlate metal artifacts with their potential sources have been few and limited in nature. Sana Ullah (1940) compared the bulk chemical compositions of copper ores from deposits in Afghanistan and India to copper artifacts from Harappa and suggested that, based on the presence of nickel and arsenic, Harappan copper was probably derived from sources in Rajasthan. Much later Hegde and Ericson (1985) made seven Pb isotope assays on samples of chalcopyrite and galena from deposits in Rajasthan. Although their work was an important first-step for provenience research of this kind, they did not follow up with analyses of additional sources samples or, more importantly, of artifacts that could have been correlated with potential ore sources.

In an effort to advance this line of research another step forward, in this chapter, I compare metal artifacts from Harappa and eight other prehistoric sites to various metal ore deposits in Pakistan, India, Oman and Iran using *lead isotope analysis*. Geologists and archaeologists working in these areas have already isotopically assayed many of the lead, lead-silver and copper sources that would have been accessible to the ancient peoples of these regions. Here, previously published lead isotope data are compiled and presented along with the results of nearly 150 new assays of geologic source samples conducted specifically for this study. Together, these provide reasonably representative geologic databases, which I use to make provisional geologic provenience determinations for 86 metal artifacts or archaeological ore minerals composed of or containing lead. I have determined that, among other things, residents of Harappa acquired lead resources from deposits in at least three regions: Jammu and Kashmir, southern Balochistan and one other source area that has yet to be identified.

I begin this chapter by reviewing some of the forms in which the element lead (denoted by the abbreviation "Pb" – from the Latin "plumbum") is found in both nature and in archaeological materials. A discussion of Pb isotopes and the technique used in this study to sample and measure them follows. Next, an explanation of how isotopic data are evaluated and displayed is provided. At that point, the Pb isotope database for lead deposits is presented in a region-by-region overview of isotopically assayed ore occurrences. After the potential lead sources have been evaluated and readied for comparison, the results of Pb isotope assays made for all of the lead ores, finished artifacts, slags and residues from Harappa are plotted in relation to them and provisional geologic provenience determinations are made. Assays of lead and/or silver artifacts from the sites of Mohenjo-daro, Allahdino, Nagwada, Gola Dhoro, Mehrgarh, Nausharo, Mundigak and Shahr-i-Sokhta are also evaluated in relation to the lead database. Finally, seven archaeological copper ore fragments from Harappa are compared to a second Pb isotope

database put together from published data and new analyses of copper ores and slags collected previously unassayed copper deposits. In the conclusion of this chapter, I briefly discuss how these results inform our understanding of the lead, silver and copper acquisition networks in which Indus Civilization peoples, especially those at Harappa, were involved.

## LEAD, LEAD ARTIFACTS AND ARTIFACTS CONTAINING OR DERIVED FROM LEAD

Lead, like most other metal elements (gold excepted), is relatively uncommon in its native state and instead is usually found mineralized in sulphide deposits (Rapp 2002: 140). Within those deposits its most common form is the mineral galena – lead sulphide (PbS) (Deer *et al*. 1992: 604). Galena frequently co-occurs with sphalerite (zinc sulphide) and also sometimes contains significant amounts of copper, silver and antimony (ibid.). Cerussite ($PbCO_3$), anglesite ($PbSO_4$) and massicot (PbO) are all common alteration products of galena and are typically found along the weathered margins (gossan) of lead deposits that are adjacent to calcareous rocks (Guilbert and Park 1986: 811).

Archaeologically, lead has been found in several forms at Indus Valley and Balochistan Tradition sites. Finished items made of this metal include small vessels and utensils, hooks, cones or "plumb bobs," rods, rings and ingots (Francfort 1989: 147-148; Kenoyer and Miller 1999: 119; Mackey 1938: 453; Lal 1985: 656; Ratnagar 2004: 197). Raw, unmodified lead ores of various kinds have been found at several sites as well as lead slags and non-descript lumps (Hargreaves 1929: 33; Mackay 1943: 188; Marshall 1931c: 30). Lead residues that may be the remains of cosmetics or pigments are also known (Sana Ullah 1931: 691).

Even though it is not readily apparent, the element lead is often present in objects made predominantly of other metals. For instance, it occurs as a natural impurity in copper ores such as chalcopyrite (Deer *et al*. 1992: 595) and copper objects made from such ores usually retain trace amounts of lead. In addition, lead is often deliberately added as an alloy during manufacture of copper alloy items (Agrawal 1971). Metals extracted from lead ore might also be expected to retain a trace amount of the element. The term *argentiferous* describes metals ores (lead or copper) with a high silver content. Silver artifacts have been found at many Indus Civilization sites and it has often been suggested that much of that metal may have been derived from the smelting of argentiferous lead ores (Asthana 1993: 276; Ratnagar 2004: 193; Pascoe 1931: 675; Sana Ullah in Mackay 1938: 599).

Determining the sources of lead, whether it occurs as a finished item, a raw ore, residue or trace component of an artifact made of another metal like silver or copper, can provide important insights into long-distance acquisition networks in which the residents of Harappa were involved. As is demonstrated below, it is possible to determine the geologic provenience of lead artifacts (and perhaps copper and silver ones too) using lead isotope analysis (Agrawal 2000: 30; Ratnagar 2004: 195).

## LEAD ISOTOPE ANALYSIS

The element lead (Pb) has four isotopes ($^{208}Pb$, $^{207}Pb$, $^{206}Pb$, $^{204}Pb$) that vary in absolute amounts depending on its geologic age and the conditions in which it mineralizes (Guilbert and Park 1986: 286-90). Thus, Pb isotope analysis has long been employed in the geosciences to determine the age and evolutionary environment of ore deposits (Doe and Zartman 1979). This analytical technique has also been effectively applied to the study of archaeological metals over the past 30 years (Lambert 1997: 188-191).

The main reason for this is that Pb isotopes do not undergo physiochemical fractionation when an ore is smelted or when the extracted metal is fashioned (and re-fashioned) into finished products (Budd *et al*. 1995: 127). Thus, an artifact containing lead from a *single* deposit will retain the original isotopic composition of that deposit. Although it is a problematic possibility that alloyed and/or recycled metal artifacts may contain lead derived from multiple sources, Pb isotope data are, nonetheless, extremely useful for archaeological studies attempting artifact-to-ore source correlation.

Measuring the abundance of the four isotopes of lead within a geologic or archaeological sample is done with a mass spectrometer. Until fairly recently, the majority of Pb isotope analyses were conducted using a thermal ionization mass spectrometer (TIMS) – an instrument which still today produces the most accurate and precise measurements (Pomies *et al*. 1998). All of the previously published isotope values for geologic samples presented in Appendix 12.1 were made using a thermal ionization mass spectrometer (TIMS). Measuring Pb isotopes using an inductively coupled plasma mass spectrometer (ICP-MS) is, however, becoming increasingly more common (Pollard and Heron 1996). Although the analytical error factor for ICP-MS isotope measurements is somewhat larger than for TIMS, data derived using both techniques can be, and have been, used together effectively (Attanasio *et al*. 2001; Ingo *et al*. 1997).

### EDTA sampling of lead and silver artifacts and analysis using ICP-MS

Most of the new Pb isotope assays of geologic and archaeological lead and silver samples made for this study were conducted using the ICP-MS at the LARCH. A handful of analyses were made using a Neptune multi-collector ICP-MS at the Keck Isotope Laboratory, UC-Santa Cruz. In order to get lead from samples into a liquid solution for analysis, a new technique (Figure 12.1) was used that employs ethylenediaminetetraacetic acid (EDTA) – a hexadentate chelating agent that forms coordinate bonds with lead atoms (Law and Burton 2008; Law and Burton 2006a; Reslewic and Burton 2002). A non-toxic sampling solution is prepared that consists of ultra-pure water and 0.05% dissolved EDTA (Figure 12.1 A). A lead artifact that has previously been cleaned in purified water is placed into a disposable plastic sampling tray and approximately 50 ml of the sampling solution is poured into the tray, immersing the artifact (an inscribed lead bar from Harappa [H2000/2174-321] is pictured in Figure 12.1 B). The sample remains in the solution for two minutes while the tray is lightly agitated at 20 second intervals. This short immersion time is sufficient to extract lead from a sample in concentrations from 100 ppb to as much as 100 ppm – orders of magnitude more than minimally required for ICP-MS analysis. After two minutes, the now lead-enriched solution is poured into a sample vial for return to the lab (Figure 12.1 C). The artifact is rinsed in ultra-pure water, allowed to dry and then returned to its place of storage or display. Although this sampling method is technically destructive (Pb atoms form 1:1 bonds with the EDTA and are removed from a sample), the short immersion time in the sampling solution does not result in any macroscopic alteration of lead or silver artifacts whatsoever.

Lead-enriched solutions sampled from archaeological and geologic materials (sites and locations to be discussed) were returned to Madison and analyzed on the ICP-MS in groups of five. For accurate counting statistics, 107 counts per second (approx. 10 ppb) were required against a background of approximately 104 counts per second. An EDTA-sampled solution of the NIST Common Lead Isotopic Standard (SRM 981) was assayed before and after each group run. Based on repeated measurements (n=44) of this standard, the overall *precision* (Figure 12.1 D) – an expression of analytical error based on the relative standard

**Figure 12.1** A technique for non-destructive Pb isotope sampling and analysis of lead and silver artifacts using ethylenediaminetetraacetic acid (EDTA) and ICP-MS.

**A**. A non-toxic solution of purified water and 0.05% EDTA is taken to the site or museum at which a lead or silver artifact is stored.



**B**. The artifact is placed in a small tray; the EDTA solution is poured over it and is then left to sit for two minutes.



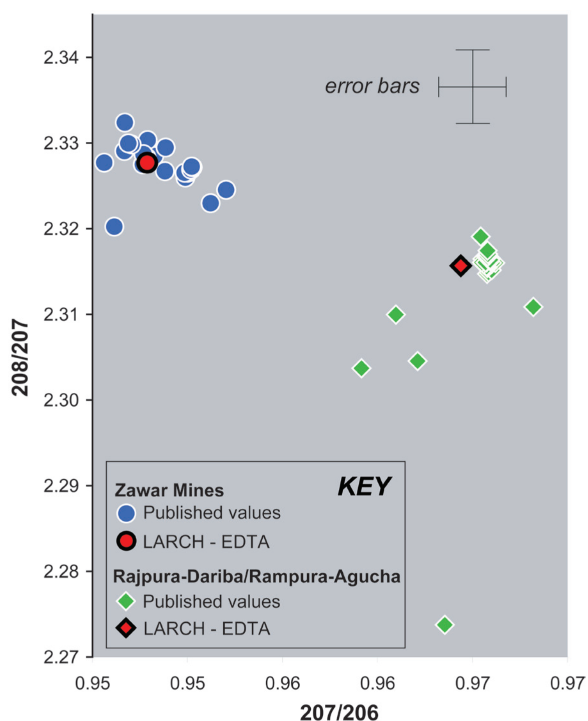
**C**. The now lead-enriched solution is put into a sample vial and the artifact is washed, dried and returned to the collection.



**D**. Solutions are analyzed with an ICP-MS. The analytical **precision** (below) of the instrument was determined by repeated measurements of NIST Lead Isotopic Standard SRM 981.

| | 208/207 | 207/206 | 207/204 |
|---|---|---|---|
| NIST Standard | **2.3696** | **0.9150** | **15.4970** |
| mean of 44 measurements | 2.3724 | 0.9157 | 15.5544 |
| SD of mean | 0.004384 | 0.00175 | 0.13352 |
| Precision (%RSD) | 0.19% | 0.19% | 0.86% |

**E.** The **accuracy** of this technique was gauged (right) by analyzing ore samples from deposits that had already been well characterized using TIMS. EDTA/ICP-MS derived isotope values for samples from the Zawar and Rajpura-Dariba/Rampura-Aguchalead bodies closely matched previously published (Deb et al. 1989) TIMS data.




deviation (%RSD) of all of those measurements, was calculated to be under 0.2% for ratios constructed (discussed below) using the isotopes $^{208}$Pb, $^{207}$Pb and $^{206}$Pb. It was significantly higher (0.86%) for ratios using $^{204}$Pb. Although considerably less precise than TIMS, which typically produces measurements with a precision of 0.005 to 0.01 %RSD (Heumann *et al.* 1998), the ICP-MS has, nonetheless, provided values (for all ratios except those using $^{204}$Pb) for which it is possible to be confident of to at least three significant

digits. Furthermore, the frequently assayed NIST standard has been used to adjust (correct) measured isotopic values on the samples to more accurately reflect what their true values likely are. This was done by taking the average of the values measured for the two bracketing standards (one run before and one after five samples), calculating how that average varied from the set NIST standard and then adjusting the measured values on the samples by the difference.

In order to gauge the accuracy of this technique and the corrections applied to the data it provided, one galena sample each from two isotopically well-characterized lead occurrences in southern Rajasthan – Zawar and Rajpura-Dariba/Rampura-Agucha, was analyzed using the EDTA/ICP-MS method. The data were compared to the published TIMS produced values from those two ore fields (Deb *et al.* 1989). In both cases, the corrected EDTA/ICP-MS isotopic values for the geologic test samples closely matched those of the highly accurate TIMS method (Figure 12.1 E).

Although not as precise as TIMS, there are many advantages to using a combination of EDTA sampling and ICP-MS for the analysis of lead artifacts. Sampling using this technique is, for all practical purposes, non-destructive. No material need be chipped off or scraped from an artifact for digestion in acid. Although EDTA sampling is "destructive" in the sense that some Pb ions are physically removed from the surface of the sample, this only takes place at an atomic level. Macroscopic alteration of artifacts is in no way evident. Ease, speed and cost of sample preparation and analysis are other advantages. Preparing lead samples for TIMS is an extended and laborious process that results in such analyses being quite expensive and time consuming. The EDTA/ICP-MS method is considerably less difficult and comparatively less expensive. No hazardous acids or purification columns need be used. The simple and short sample preparation process and the ease of ICP-MS (as compared to TIMS) help keep the cost of isotopic analysis using this method reasonably low. A final advantage is that artifacts sampled for Pb isotopes in this way need not be removed from location at which they are stored. A small kit containing purified water (for artifact cleaning before and after sampling), the non-toxic EDTA solution, disposable containers (for artifact immersion in the solution) and vials (for holding the sampled solution) can be taken directly to a site being excavated or a museum collection and lead artifacts can be quickly and easily sampled.

## Presenting and plotting Pb isotope data

Lead isotope data are normally presented as ratios of the absolute amount of one isotope against the absolute amount of another – for example $^{208}Pb/^{204}Pb$. Although only three *distinct* ratios can exist (as there are only four isotopes of lead), a dozen variations are possible depending on how one chooses to construct them. Those chosen to be presented often vary from publication to publication. Three ratios ($^{208}Pb/^{207}Pb$, $^{207}Pb/^{206}Pb$ and $^{207}Pb/^{204}Pb$) are reported in the various appendices for this chapter. If future users of this data wish to employ combinations not presented here it is possible to easily extrapolate them from the ratios provided. For example, the ratio $^{206}Pb/^{204}Pb$ may be generated simply by dividing the ratios $^{207}Pb/^{204}Pb$ by $^{207}Pb/^{206}Pb$. In the course of compiling the databases in this chapter, extrapolation was used when published isotope ratios were different from the three selected to be presented here. *Caution is advised*, however, when constructing any ratio using $^{204}Pb$ from a sample analyzed at the LARCH, as measurements made for that isotope are significantly less precise than those made for $^{208}Pb$, $^{207}Pb$ and $^{206}Pb$.

Pb isotope data are graphically represented on a bivariate plot of the values for two ratios. Since three distinct ratios exist, two such plots are required to fully display all measured data (Weeks 2004: 131). However, only one plot is used in this chapter (with $^{208}Pb/^{207}Pb$ for the *y* axis and $^{207}Pb/^{206}Pb$ for the *x*

axis) because of, once again, the imprecision of the $^{204}$Pb values for samples analyzed at the LARCH. Although omitting the third dimension by dropping $^{204}$Pb does, admittedly, create some limitations, it does not necessarily impede one's ability to discriminate between lead sources and/or to make provenience determinations. Klein and others (2004) were able to differentiate Roman lead and copper sources without using $^{204}$Pb data. In fact, when Sangster and others recently (2000) compared Pb isotope data from 151 lead deposits around the world, they found that:

> Statistical analyses suggested that while $^{204}$Pb is critical for identifying a small proportion of environmental Pb sources, about 86% of the source discrimination power is due to the $^{206}$Pb, $^{207}$Pb, and $^{208}$Pb isotopes. Thus, the requisite analytical precision, rather than a lack of $^{204}$Pb data, is the most critical issue with respect to unequivocal identification of Pb sources in most cases (Sangster *et al*. 2000: 115).

For this study, very good analytical precision overall measuring $^{206}$Pb, $^{207}$Pb and $^{208}$Pb was achieved using the EDTA/ICP-MS technique. I will show that convincing statements regarding the probable geologic proveniences of metal artifacts from Harappa and other sites can be made based a single plot generated using those three Pb isotopes alone.

## LEAD AND SILVER

Sir Edwin Pascoe, who was Director of the Geological Survey of India during the 1920s, noted that "with the exception of iron, there is perhaps no metal whose ores appear to have been worked to so large an extent in India as those of lead" and added that much of the emphasis in the exploitation of this mineral was directed toward the "extraction of silver" (Pascoe 1931: 676). Yet instead of focusing on sources in northwestern South Asia, he mentioned locations stretching from Burma to Tunisia where these metals are found (ibid.: 675-677). Although some of the places he listed are adjacent to the Indus Basin and would have been, more or less, accessible to Harappan consumers, most of the regions he states "might be looked upon as possible sources" (ibid.: 675) of lead and silver are located in South India, Afghanistan, Iran, Burma and even Armenia!

It is somewhat mystifying as to why Sir Edwin largely ignored (and presumably felt that Harappans would have ignored) the deposits of lead and lead-silver that practically ring the Indus Basin (Figure 12.2). In the intervening years some scholars have recognized the importance of these indigenous sources (Agrawal 2000; Chakrabarti and Lahiri 1996) and, in some areas, have even conducted detailed studies of ancient mining and production (Craddock *et al*. 1989). Others, however, still repeat (almost verbatim) what Pascoe wrote 75 years ago (Asthana 1993; Biwas 1996). Although I do not ignore the possibility that metals like silver were imported from sources far outside of the Greater Indus region (Ratnagar 2004: 199), here I emphasize the isotopic characterization and comparison of lead and silver deposits in closer areas where they were more "easily procurable" (Chakrabarti 1990: 143).

### The Pb isotope database of potential Harappan lead and silver sources

The Pb isotope database for lead deposits assembled here (Appendix 12.1) consists of 232 analyses made on lead ore samples from 58 individual localities throughout India, Pakistan and Oman (Figure 12.2 and 12.3). One hundred thirty-three of those isotopic determinations were drawn the geologic literature. Ninety-nine new Pb isotope analyses were conducted at the LARCH and the Keck Isotope Laboratory, UC-Santa Cruz on samples collected from previously uncharacterized (or under-characterized) lead and lead-silver deposits in Gujarat,

**Figure 12.2**: Isotopically assayed lead ore deposits of the Greater Indus Valley region and other locations discussed in this chapter. The archaeological sites from which lead or silver artifacts were analyzed for this study are noted in **red**.




**Figure 12.3**: Isotopically assayed lead sources outside of the Greater Indus Valley region.

Rajasthan, Uttaranchal, Himachal Pradesh, Jammu and Kashmir, Balochistan and Oman. Not included in the primary database are seven assays of lead slags (and a few ores) from the argentiferous galena deposit at Nakhlak, in central Iran (Appendix 12.6), which are considered only in examinations of lead and silver artifacts from sites in Iran (Shahr-i-Sokhta) and Afghanistan (Mundigak).

In the following sub-sections, potential lead and lead-silver sources are discussed on a region-by-region basis, as are important deposits that have yet to be characterized and, importantly, the ancient cultures and settlements located in those regions that Harappans would have almost certainly been directly or indirectly interacting with in order to obtain this mineral resource.

***Lead deposits in Balochistan***

In Pakistan's Balochistan Province, lead occurs at multiple locations within the Las Bela, Khuzdar and Chagai districts (Ahmad 1975: 63-65; Shams 1995b: 246-47). During the latter half of the third millennium BC, both Indus Civilization settlements and those belonging to the local Kulli culture, which possessed a great many traits that are considered to be typically "Harappan," could be found in the area of southeastern Balochistan encompassed by the former two districts. Although it remains to be determined if it is appropriate to characterize Kulli society as "the highland form of the Indus Civilization" (Possehl 1986: 61), it seems evident that there was a high degree of interaction taking place at this time between those dwelling in this region and the Indus Valley. The lead sources of southern Balochistan, therefore, would have likely been among the most accessible to Indus Civilization consumers. Somewhat less accessible, but still important, would have been the deposits in the Chagai district, which are located along what would

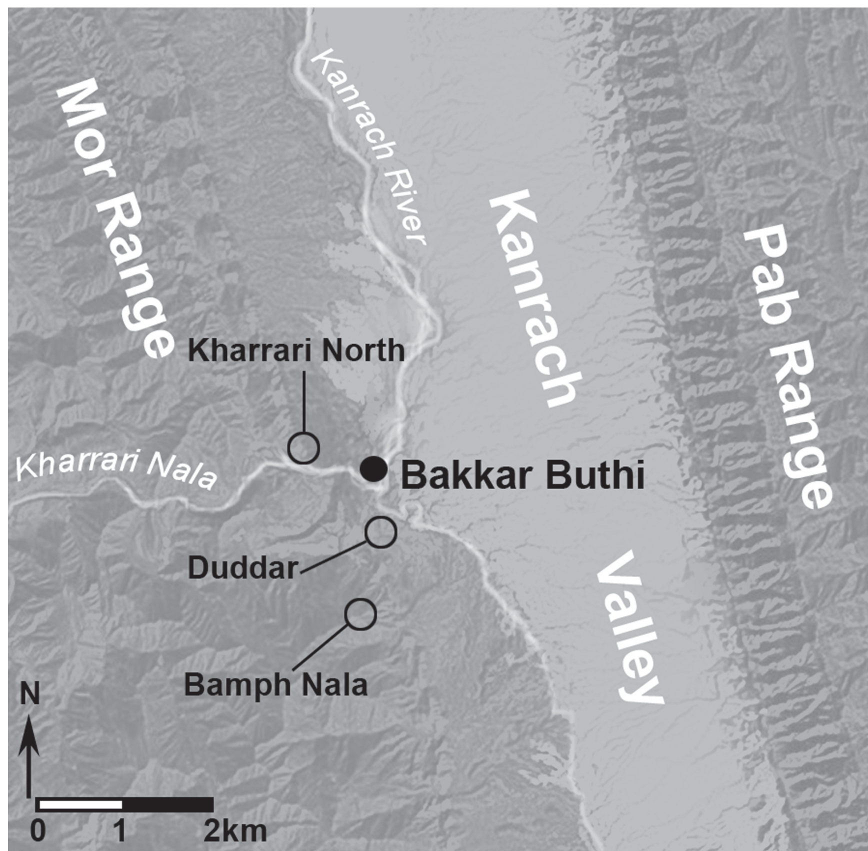



**Figure 12.4** Map of the central Kanrach Valley, Las Bela District, southern Balochistan and lead deposits sampled for this study.




**Figure 12.5** View looking north from the Duddar lead deposit, Kanrach Valley, Balochistan.



**Figure 12.6** Sampling a galena seam at Bamph Nala, Kanrach Valley, Balochistan.

have been one of the major trade and communication routes between the Indus Valley and southwestern Afghanistan and eastern Iran.

Lead mineralization can be found at several places in the Las Bela district (Ahsan and Bhutta 1991; Heron and Crookshank 1954: 93) but the largest and most economically viable deposits occur in the central part of the north-to-south running Kanrach Valley (Figure 12.4). Isotopic analyses of four galena samples from the Duddar and Kharrari areas (N 26° 05' 33", E 65° 50' 16") had been undertaken prior to this study (Bhutta 1992; Siddiqui 1994, Bhutta and Qureshi 1997). Twelve additional assays were performed at the LARCH on samples collected in May 2001 from the Kharrari North area (Figure 12.5) and a third location in nearby Bamph Nala (Figure 12.6). It is especially important to note that all of these locations are found within one to two kilometers of the prehistoric site of Bakkar Buthi, which contains both Kulli and "purely Harappan" occupation levels (Franke-Vogt *et al.* 2000: 196). A.H. Kidwai (in Heron and Crookshank 1954: 93) reported "weathered ore, slags of lead and

copper, [and] furnace clay" at a location noted at "ruins" (near Thana Kanrach) around 20 km to the north of the site. Although no such items were found during the limited excavations at Bakkar Buthi (Ute Franke-Vogt *personal communication* 2003), it is by far the nearest of all Harappan settlements to a source of lead.

Lead in the Khuzdar district (formerly part of the Kalat district) occurs at several places in the vicinity of Khuzdar town including Gunga, Shekran and Surmai (Ahmad 1975: 64; Jankovic 1986; Shams 1995b: 246; Siddiqui and Sharp 1993). Shams noted (1995b: 246) that the ore at Gunga (N 27° 44' 30", E 66° 32') was highly argentiferous, containing up to 3000 ppm silver (recall that 10 ppm is considered viably argentiferous – Craddock 1995: 211). Three isotopic analyses of galena samples from that deposit were performed by Siddiqui (1994). Two additional samples from this location were supplied by Drs. Mehrab Khan and Khalid Mahmood of the University of Balochistan - Quetta and analyzed at the LARCH. Numerous old mines and slag fields have been noted throughout this part of the Khuzdar district (Hassan 1989; Heron and Crookshank 1954: 92; Siddiqui and Sharp 1993). All are located within 25 km of the ancient mounds at Sohr Damb (Nal), where galena, cerussite, lead slags and silver artifacts have been recovered (Hargreaves 1929: 33; Yule 1995). Importantly for this study, a "Kulli-Harappan" has recently been documented at that site (Franke-Vogt 2005).

Although rich and extensive polymetallic sulphide deposits are found in the northwestern part of the Chagai District (Ahmad 1975; Shams 1995b: 243-247), showings of galena tends to be minor in nature (Kazmi and Jan 1997: 449). Nevertheless, Pb isotope assays were made at the LARCH on a total of 12 galena samples from deposits at Koh-i-Sultan (≈ N 27° 07', E 62° 47') and Rekodiq (≈ N 29° 10', E 62° 14'), which were supplied by Drs. Mehrab Khan and Khalid Mahmood of the University of Balochistan – Quetta.

***Lead deposits in the NWFP***

Lead ore in Pakistan's North-West Frontier Province (hereafter NWFP) is found primarily in the Chitral, Allai Kohistan, Swat and Hazara districts (Ahmad 1969: 39-40; Shams 1995b: 245-46). There are several reasons to believe that Harappans may possibly have obtained this metal from deposits in these districts. Numerous Early Harappan period (Kot Dijian) sites can be found in or directly adjacent to the southern parts of the province (Allchin 1984). Also, the most direct route to Shortughaï, the Indus Civilization outpost in northern Afghanistan (Francfort 1984b), would have been through the NWFP. Lastly, but certainly not least, I have already show that two other important varieties of stone – steatite (Chapter 7) and vesuvianite-grossular garnet (Chapter 9), seem to have been acquired from sources located in this region.

Lead mineralization, sometimes co-occurring with copper and antimony, has been noted at nearly a dozen locations in the southern part of the Chitral district (Ahmad 1969: 39-40). Tahirkheli and others (1997) performed Pb isotope analysis on three galena samples from a zone of copper mineralization in the Shi Shi Valley area near Drosh (≈ N 35° 39', E 71° 54'). Farther to the southeast, five Pb isotope determinations were made by Shah and others (1992) for the Lahor and Pazang lead deposits in the Besham area (≈ N 34° 56', E 72° 52'), Allai Kohistan.

Among the lead sources in the NWFP that have not yet been isotopically assayed are those near Ushu (N 35° 34', E 72° 43') in the Swat district (Tahirkheli 1959) and several zones of galena mineralization around the Abbottabad area (≈ N 34° 11', E 73° 03'), Hazara district (Shams 1963; Ahmad 1969: 40). It will be especially critical to acquire material from these sources for future analysis. Early Harappan period interaction with the Swat region is suggested by finds of Kot Dijian-like ceramics at Ghalegay

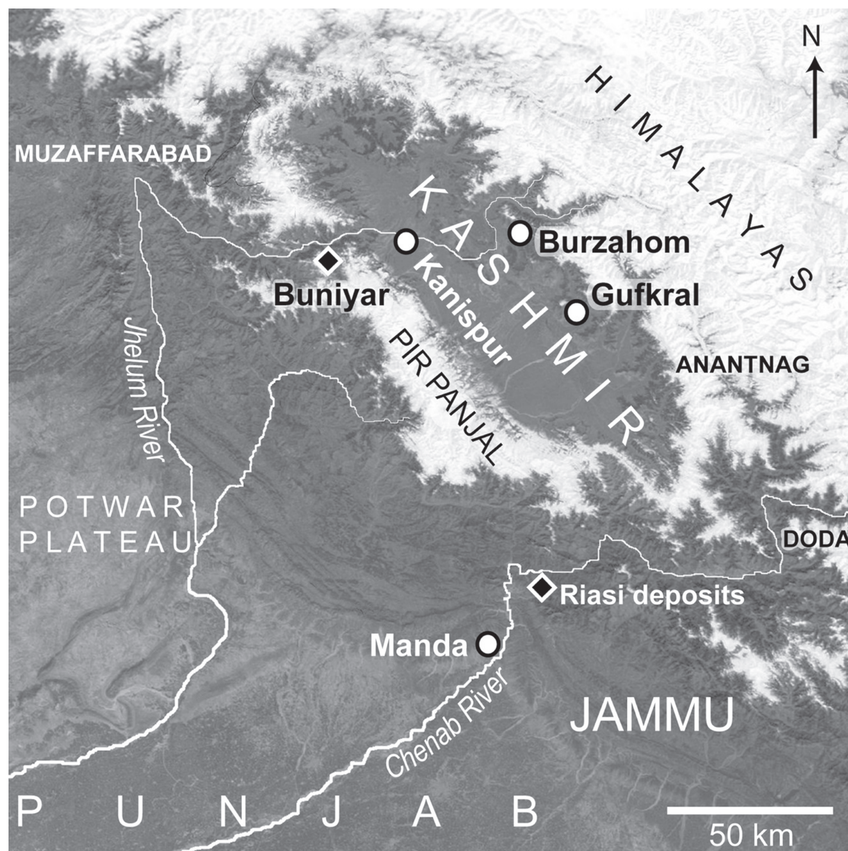



**Figure 12.7** Select sites and lead deposits in Jammu and Kashmir.

Cave (Stacul 1987: 29-49). The Kot Dijian sites of Sarai Khola, Hathial and Jhang (Khan 1983; Halim 1972) lie around 50 km or so south of the Hazara district galena sources, which themselves are situated within a few kilometers of the steatite deposits shown (Chapter 7) to have quite probably been the major source of that material for residents of Harappa.

***Lead deposits in Jammu and Kashmir***

In the Jammu and Kashmir region, lead mineralization occurs in the districts of Doda, Riasi, Baramulla, Anantnag and Muzaffarabad (Ahmed 1997; Srivastava 1977; Varadan 1977: 52-54). The geologist C.S. Middlemiss noted (1929: 2) that the "lead-silver deposits of the State [*appear to*] have been worked in a primitive way during ancient times." Importantly, some of these deposits are located (Figure 12.7) in the vicinity of Indus Civilization settlements and/or along the natural routes through which Northern Neolithic and Kot Dijian/"Late" Kot Dijian phase peoples interacted with one another.

Sporadic occurrences of lead-zinc are found within the Great Limestone formation of the Riasi district (Nayak and Sharma 1991). Four galena samples from abandoned workings near Sersendu village (N 33° 06' 53", E 74° 54' 00") were isotopically assayed by Raha and others (1978). Additional assays were made at the LARCH on 11 samples from this same area. I collected six of those from an old mine at Kheri Kot (on the ridge above Sersendu) in June of 2003 (Figure 12.8). Five more were provided by Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology who collected them from the nearby Darabi area. The Riasi deposits are among the closest lead sources to Harappa and are located less than 30 km north of Manda, where Joshi and Bala (1982) identified both Early Harappan and Harappan occupational phases.

In the Baramulla district, lead can be found at various places in the Buniyar area along Hapatkhai Nala (≈ N 34° 06', E 74° 12'), about a kilometer south

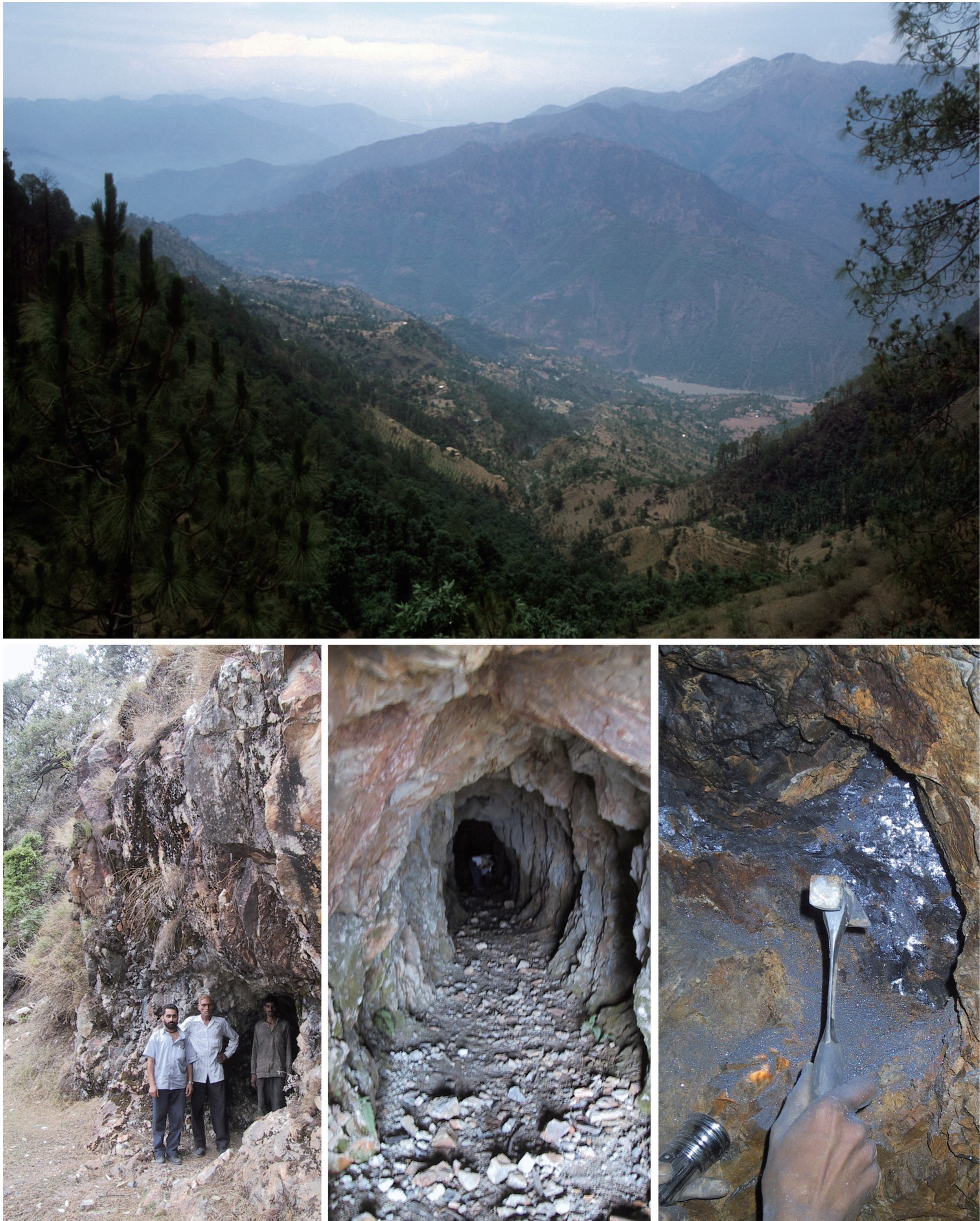


**Figure 12.8** Top - View from Kheri Kot looking north, above Sersendu Village and the Chenab River. Bottom images - Visiting one of the old lead mines at Kheri Kot and sampling galena.

the Jhelum River (Middlemiss 1929; Raina 1977). The Jhelum River is an important route connecting the Kashmir Valley to the Potwar Plateau and upper Indus Basin. The cache of carnelian beads in a Kot Dijian style pots recovered at the Northern Neolithic site of Burzahom (Pande 2000) provides clear evidence for interaction and exchange between the ancient peoples of those regions. Lead from the Buniyar area, which sometimes contains minor amounts of sphalerite and chalcopyrite in addition to galena (Sharma and

Sachan 1998), could have been an important trade good for Northern Neolithic Phase Kashmiris, who were settled as near as 20 km to the northeast at Kanispur (Mani 2000). Pb isotope determinations were made at the LARCH on seven galena samples from the Buniyar occurrences provided by Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology at Dehra Dun.

Several lead sources in Jammu and Kashmir have yet to be isotopically characterized. At Treri (N 34° 26' 48", E 73° 43' 10") in the Muzaffarabad district, galena is found with zinc and copper (Ahmad *et al.* 1992; Ahmed 1997). Nodules of galena can be found at Hapatnar (N 33° 50', E 75° 21') and Shumahal (N 33° 50', E 75° 17') in the Anantnag district (Varadan 1977: 52). In the Doda district, galena and cerussite are found near Chichhe village as are old workings for those minerals (Srivastava 1977).

***Lead deposits in Himachal Pradesh and Uttaranchal***

D.P. Agrawal argued (1999) that the central Himalayas were an important, but largely overlooked, region with regard to the study of South Asian archaeometallurgy. Indeed, the states of Uttaranchal and Himachal Pradesh are exceptionally rich in both base and noble metals. Geologists have noted the existence of scores of disused mine shafts, pits, slag heaps and waste dumps that indicate the varied deposits of the region were widely exploited in former times (Sharma 2002). Ropar, Bara and Kotla Nihang Khan are all proto-historic settlements found within 10 km of the point near which the Sutlej River leaves the foothills of the lesser Himalayas (Sharma 1982). Harappan period remains were also unearthed at Chandigarh, not far from where the Ghaggar River meets the plains (Joshi 1990: 15). Indus Civilization peoples dwelling at any of these sites would have been well positioned (Figure 12.9) to access the rich lead-silver deposits of the central Himalayas.

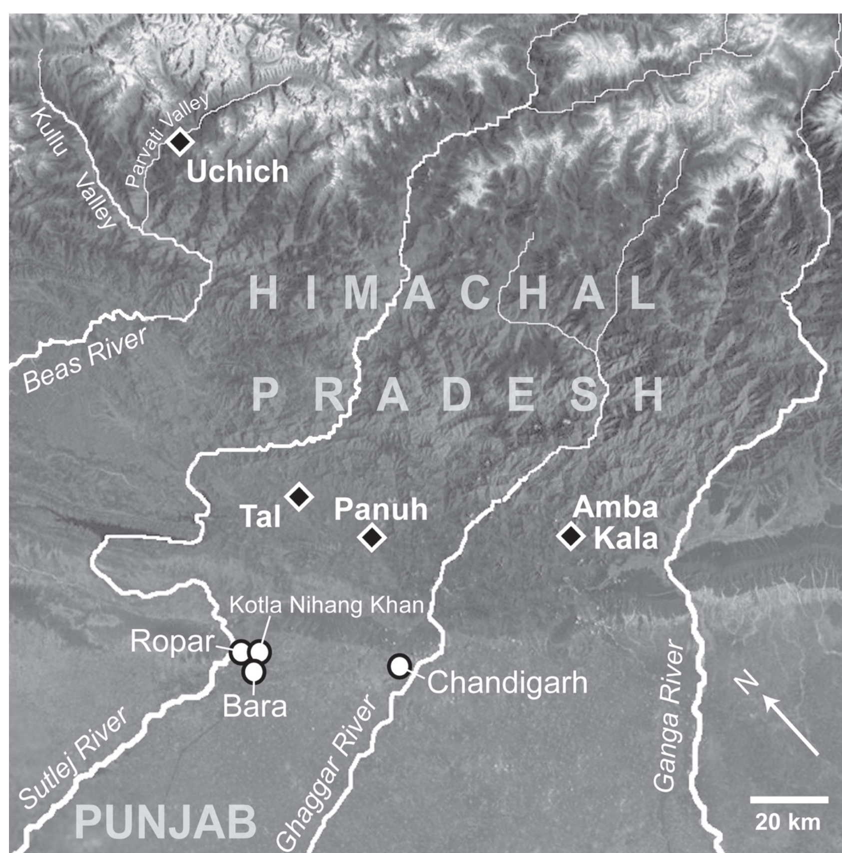



**Figure 12.9** Select Himachal Pradesh lead deposits and Punjab archaeological sites.

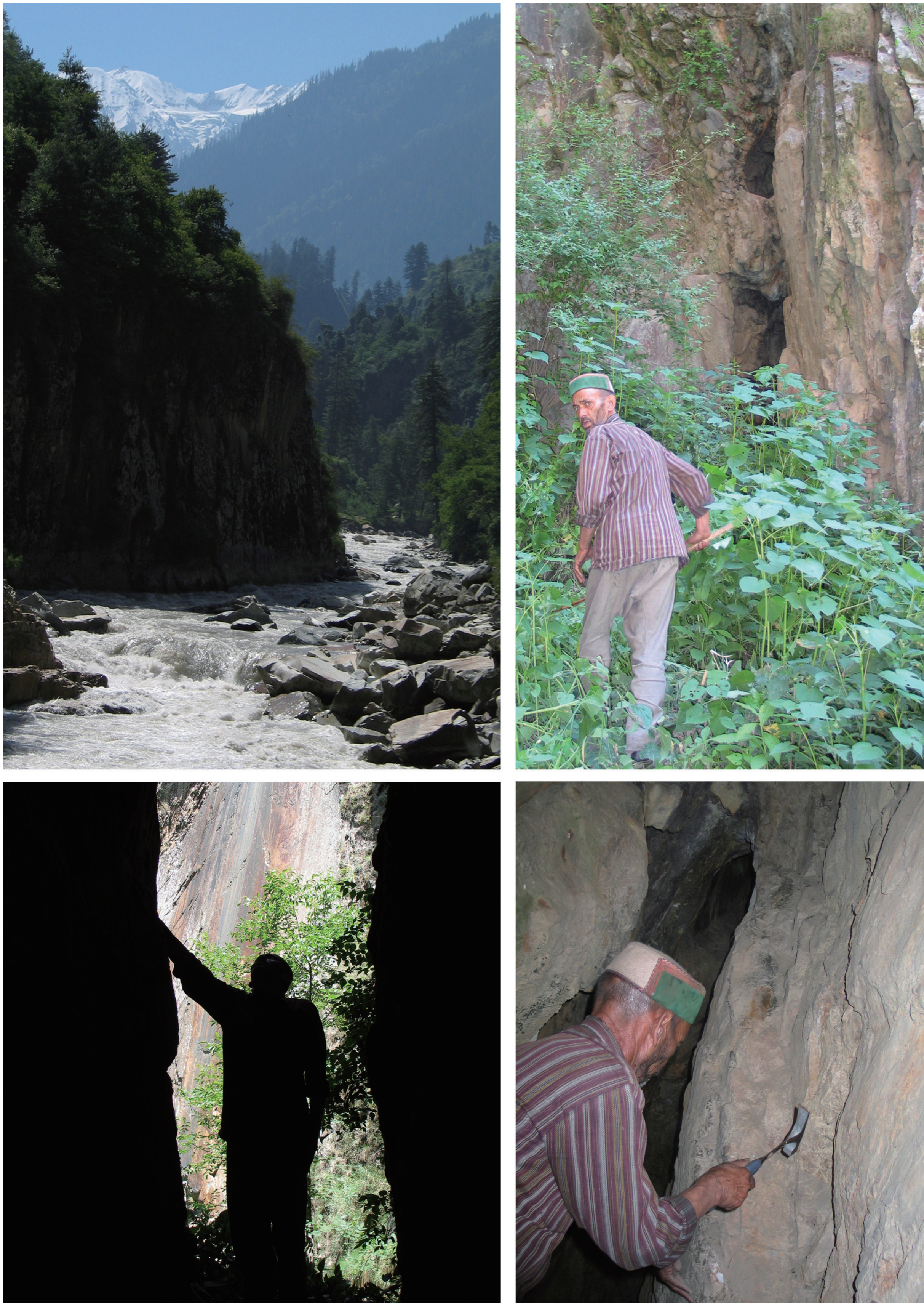


**Figure 12.10** Sampling trip to the old silver mine at Uchich, Parvati Valley, Kullu District, Himachal Pradesh.



**Figure 12.11** Old working and lead sample taken at Amba Kala, Himachal Pradesh.

In Himachal Pradesh, lead deposits occur in the Kinnaur, Kullu, Simla and Sirmaur districts (Chowdhury and Sehgal 1962; Geological Survey of India 1989a: 32-33; Srikkantia and Bhargava 1998: 335-36). Prior to this study, no Pb isotope determinations had been made for any of the deposits in the state, many of which are highly argentiferous. The lead mines in the Kullu Valley and others adjoining it have long been famous as sources of silver (Calvert 1873). Five Pb isotope determinations were made on samples collected (Figure 12.10) in June of 2004 from the old silver mine at Uchich (N 32° 00' 41", E 77° 22' 27") near Manikaran in the Parvati Valley, Kullu (formerly Kangra) district (Sehgal 1964). Samples were also collected at that time from the galena mines at Panuh (N 30° 58' 12", E 77° 01' 15") and Tal (N 31° 09' 57", E 76° 57' 18") in the Solan district (Chattopadhyay and Verma 1992; Kumar 1992). Ten Pb isotope analyses for the Panuh deposit and five for the Tal deposit were conducted at the LARCH. Galena at Amba Kala (N 30° 38' 29", E 77° 27' 24") in the Sirmaur district is reported to contain up to 250 ppm silver (Geological Survey of India 1989a: 49). Five Pb assays were made on samples collected from that deposit (Figure 12.11) in May of 2003.

Although lead mineralization occurs across Uttaranchal, the richest deposits are found in the eastern portion of the state in the Kumaun region (Valdiya 1980: 263). Many of these deposits are highly argentiferous, such as the one near Birgana village, Garwal District (Shrivastava and Kapoor 1981). Sarkar and others (2000) assayed three galena samples from the lead-copper deposits found in the vicinity of Bageshwar (≈ N 29° 48', E 79° 46') (Banerjee 1977; Srivastava and Gaur 1979). Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology, Dehra Dun supplied galena samples from two additional Kumaun region deposits for Pb isotope analysis at the LARCH. Three samples were from the polymetallic sulphide deposit at Askot (≈ N 29° 46', E 80° 20') in the Pithoragarh district near the border with Nepal (Acharya 1988; Ghose 1976). Two samples came from an area of galena mineralization at Khansue, Okhalkanda subdivision, Nainital district.

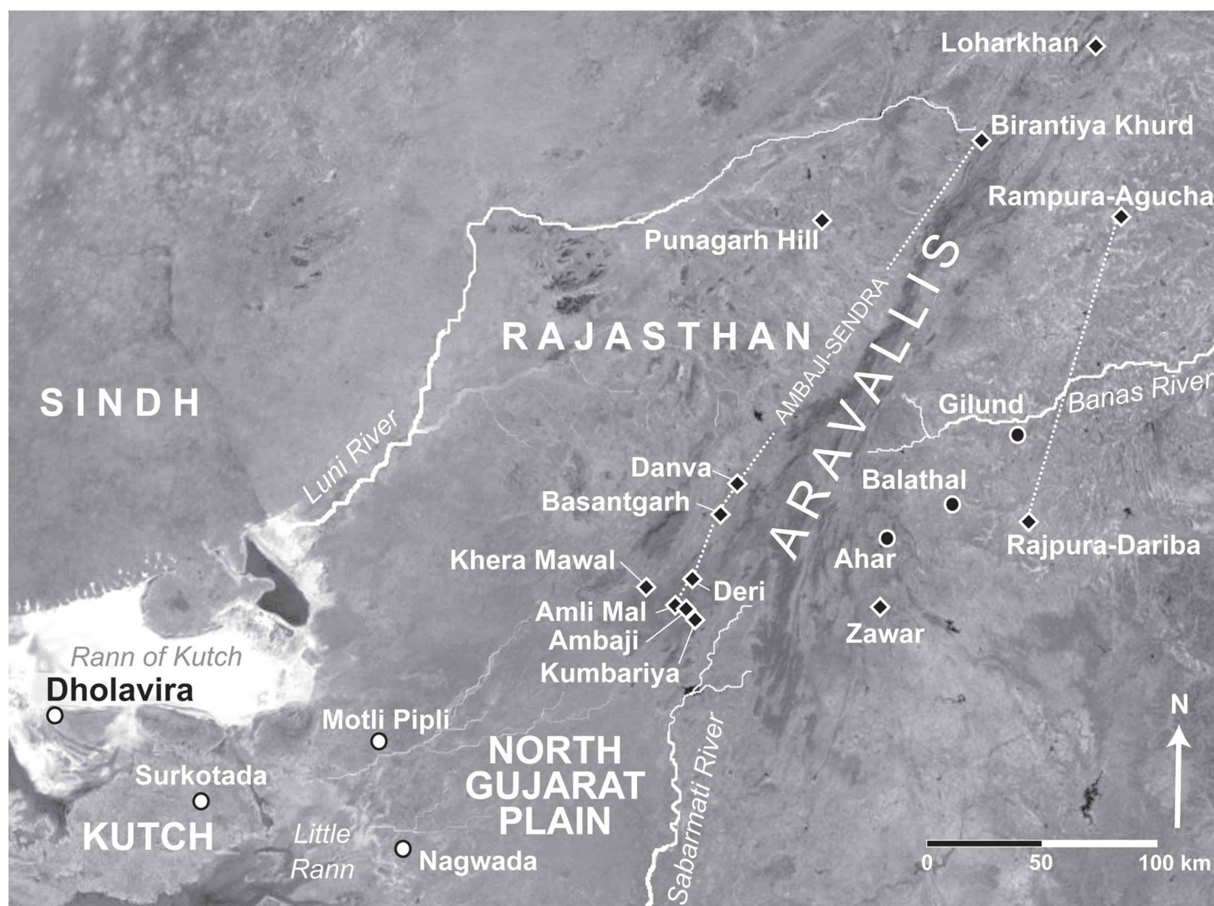



**Figure 12.12** Isotopically assayed lead sources and select Harappan and Ahar-Banas sites in the southern Rajasthan and northern Gujarat regions.

*Lead deposits in Rajasthan and Gujarat*

The base metal deposits of Rajasthan are extensive and numerous. There is evidence they were exploited beginning at least as far back as the Early Historic period of South Asia. Lead mineralization can be found in the Udaipur, Rajsamand, Bhilwara, Sirohi, Ajmer, Sawai Madhopur, Chittorgarh, Pali, Banswara and Bharatpur districts (Geological Survey of India 1994; Indian Bureau of Mines 1995: 29-38). In this section, only those deposits that have been isotopically characterized are discussed.

The Khetri copper belt is the dominant zone of sulphide mineralization in northern Rajasthan (Geological Survey of India 1994: 2-34) and was almost certainly a major source of that metal during the Harappan period (Agrawala 1984). Sites belonging to the Ganeshwar-Jodhpura culture complex are found across this region. Stylistic analyses of copper arrowheads suggest that there were contacts between peoples of that phase and Harappans (Rizvi 2007: 152). However, is unlikely that much, if any, of the raw lead used by Indus Civilization peoples was derived from northern Rajasthan sulphide deposits. The only location where galena mineralization can be found in the Khetri copper belt is on its southern margins at Saladipura (N 35° 34', E 72° 43') in the Sirohi district. There it occurs in trace amounts together with sphalerite and pyrite (Das Gupta 1970). Two Pb isotope analyses of galena from this location were conducted by Deb and others (1989).

Although the zone of mineralization is largely obscured under the alluvium, "extensive old workings for galena" are still evident at Chauth-ka-Bawara (N 26° 02' 59", E 76° 11' 05") in the Sawai Madhopur district (Geological Survey of India 1994: 135) of eastern Rajasthan. Five galena samples collected from



**Figure 12.13** Old lead mine shaft and smelting slags at Rajpura-Dariba, Udaipur District, southern Rajasthan.

this deposit in June of 2004 were analyzed at the LARCH.

The largest concentration of lead deposits in this database is situated in the southern Rajasthan/northern Gujarat region. A supplementary map (Figure 12.12) is provided for the discussion of potential sources in this region. Individual locations in the Ambaji-Sendra sulphide belt are identified as well as important Harappan and Ahar-Banas complex sites.

Lead occurs at numerous locations within the Ajmer and Pali districts of central Rajasthan (Geological Survey of India 1994: 53-62). Old workings are found (N 26° 29' 08", E 74° 39' 10") on the outskirts of Ajmer city at Lohakhan (Nath 1972). One sample collected at this location in January of 2004 was analyzed at the LARCH. Abandoned mine shafts penetrating as deep as 40 m can be seen at Punagarh Hill (N 25° 48', E 73° 26') in the Pali district (Gupta 1977; Sahai *et al.* 1997: 180). Two galena samples from this location were analyzed by Deb and others (2001).

The lead deposits of the Udaipur, Rajsamand and Bhilwara districts of Rajasthan are the richest in India and the most isotopically well characterized. Twenty-one Pb isotope determinations have been made (Balasubramanyan and Chandy 1976; Deb *et al.* 1989) on galena samples from the lead-zinc deposit at Zawar (N 24° 20', E 73° 41') in the Udaipur district. Evidence suggests that mining and beneficiation of ores from this deposit began around 2000 years ago (Freestone *et al.* 1985; Craddock *et al.* 1989). Collectively there have been 31 isotopic determination made (Balasubramanyan and Chandy 1976; Deb *et al.* 1989; LARCH 2004) on galena samples from the Rajpura-Dariba lead belt (≈ N 24° 38', E 74° 18') in the Rajsamand district and the Rampura-Agucha deposit (N 25° 49', E 74° 43') in the Bhilwara district. Occurring in the same geologic terrain, these two zones of polymetallic sulphide mineralization are isotopically indistinguishable and so are treated as a single source in this study. The lead from both the



**Figure 12.14** Sampling galena at Khera Mawal, Banaskantha District, northern Gujarat.



**Figure 12.15** Top images - Modern lead-zinc-copper mine at Ambaji, Banaskantha District, northern Gujarat and a galena speckled sample taken at that location. Bottom images - Smelting slags near Ambaji at Kumbariya.

Rajpura-Dariba and Rampura-Agucha deposits is richly argentiferous (Mukherjee *et al.* 1991; Lahiri and Ravindranath 1988) and there is abundant evidence (Figure 12.13) for mining and smelting at those locations extending as far back as the mid-second millennium BC (Willies 1989). If it is could be shown that Indus Civilization peoples might have obtained some of their lead and/or silver from these

sources then it would provide compelling evidence of long-distance interaction with peoples belonging to early phases of the Ahar-Banas culture of southern Rajasthan (Chakrabarti 1968; Fairservis 1975: 335-340; Shinde *et al*. 2005).

In the Sirohi district near the border with Gujarat, pockets of galena are found at Khera Mawal (N 24° 24' 37", E 72° 42, 46") intermittently along a 500m zone (Geological Survey of India 1994: 68). Deb and others (2001) produced a single isotope determination for a galena sample from this location. Data for two additional samples was produced at the Keck Isotope Laboratory, UC-Santa Cruz after the deposit was visited in January of 2004 specifically for this project (Figure 12.14).

Beginning on the northern border of Gujarat at Ambaji and extending approximately 240 km into southern Rajasthan near Sendra is a geologic terrain that contains many areas of massive sulphide mineralization (Deb *et al*. 2001). Old workings, mine dumps and slag fields (Figure 12.15) are founds at numerous locations across this zone (Murty and Shekar 1975: 32; Sahai *et al*. 1997: 182; Geological Survey of India 1994: 34; *personal observations*). Sixteen Pb isotope determinations in total have been made (Deb *et al*. 1989; Deb *et al*. 2001; LARCH) on ore samples from following locations within the Ambaji-Sendra sulphide belt: Ambaji (N 24° 20' 43", E 72° 50' 48"), Amli-Mal (N 24° 21' 53", E 72° 48' 22"), Kumbariya (N 24° 18' 36", E 72° 53' 48"), Danva (N 24° 46' 10", E 73° 02' 10"); Deri (N 24° 20' 43", E 72° 50' 48"), Basantgarh (N 24° 43' 30", E 73° 01' 15") and Birantiya Khurd (N 26° 07', E 74° 08'). The Indus Civilization peoples at sites like in north Gujarat like Dholavira or Nagwada might have accessed these deposits directly or via interaction with hunter-gatherer groups of the North Gujarat Plain (Possehl 1980: 73).

Lead mineralization is much more minor in nature elsewhere in Gujarat. The sporadic occurrences that do exist, however, could conceivably have been exploited by the Harappan or related cultures of



**Figure 12.16** Sampling the lead occurrence at Khandia, Vadodara District, eastern Gujarat.

the region (Ajithprasad 2002; Possehl 1980, 1992; Sonawane 2002). A small deposit of galena (Figure 12.16) is located near Khandia (N 22° 19' 26" E 73° 33' 39") in the eastern part of the Vadodara district (Shah *et al.* 1985; Yellur 1969). Five isotopic analyses of samples collected from this deposit in May of 2003 were performed at the LARCH. In the Junagadh district of southern Saurashtra, galena together with specks of chalcopyrite (Shekar and Mukul 1969) is found in the Gir Forest near Banejnes (N 21° 03' 15", E 70° 53, 48"). Five isotopic analyses of samples collected from this deposit in May of 2003 were performed at the LARCH.

Lead occurs with pyrite in the Amba Dongar fluorite deposit of southeastern Gujarat (Simonetti and Bell 1995). A single sample of galena from this deposit was assayed by Venkatasubramanian and others (1982).

***Lead deposits elsewhere in South Asia***

In this section, I briefly review Pb isotope analyses of galena from deposits in South Asia that are either minor in nature or not encompassed by the current study area – the Greater Indus region. Although many of these deposits were probably not utilized by Harappans, in the interest in producing a comprehensive database, these data are included in the appendix and plotted on the accompanying charts.

Deb and others (2001) made a single Pb isotope determination on galena from the polymetallic ore deposit at Tosham Hill (N 28° 52' 32", E 75° 54' 41"), district Bhiwani, Haryana. This deposit has been proposed as a possible source of tin for the Indus Civilization (Kochhar *et al.* 1999). However, only trace amounts of galena occur with the other metals found there (Awasthi *et al.* 1981). Although Tosham Hill cannot be ruled out as a source of Harappan lead, it is unlikely that much, if any, galena was extracted from this location.

In total, 15 Pb isotope analyses have been made on galena samples from deposits in eastern India. In the state of Bihar, three isotope determinations exist for the lead deposit at Amjhor (Balasubrahmanyan and Chandy 1976) and five for those in the Hesatu-Pindura sulphide belt (Singh *et al.* 2001). Three samples from Gorubathan, West Bengal and four from Rangpo, Sikkim have also been analyzed (Sarkar *et al.* 2000). All of these deposits are over 800 km away from the easternmost Harappan site. It seems highly unlikely Harappans would have exploited these sources when much closer ones were at hand.

Lead minerals occur in many parts of southern India (not pictured on Figure 12.3). Venkatasubramanian and others (1982) conducted isotopic analyses on individual galena samples from various deposits in the states of Andhra Pradesh, Karnataka and Tamil Nadu. For her provenience study of the Early Historic Period South Indian bronze icons, Srinivasan analyzed (1999) nine samples from the lead occurrence at Agnigundala, Andhra Pradesh.

***Lead deposits in Oman and Iran***

One area outside of the Greater Indus region to which Indus Civilization peoples travelled is the eastern part of the Arabian peninsula. Harappan artifacts have been recovered at a number of coastal and inland sites located present-day Oman and the United Arab Emirates (Cleuziou 1984, 1992; Cleuziou and Vogt 1985). Part of the impetus for Indus peoples to make such a distant journey may have been the acquisition of metals, in particular copper, from the region's rich sulphide deposits (Weisgerber 1984). However, although a fair amount of Pb isotope data exists for eastern Arabia, most of the analyses made to date have been conducted on pyrite, chalcopyrite or various volcanic rocks (Calvez and Lescuyer 1991; Chen and Pallister 1981; Prange 1999; Stos-Gale *et al.* 1997). I have located only three published Pb-Pb determinations made on lead minerals from Oman – a single sample each from Wadi Mayh (≈ N 23° 25'



**Figure 12.17** Sampling the old lead mine at Wadi Nujum, Oman.

53", E 58° 33'), Qumayrah (N 23° 55' 57", E 56° 11' 42") and a section of the Semail ophiolite near Ibra (N 22° 41' 25", E 58° 32' 04"). Insofar as I have been able to determine, each of these occurrences are only trace showings of galena and not significant lead sources. The only viable deposit in all of Oman seems to the one at Wadi Nujum (N 23° 23' 43", E 58° 10' 44"), where an old mine (Coleman and Bailey 1981: 93-95)

and Bronze Age stone mining tools (Weisgerber 1997: 198, Figure 206) have been documented. I collected galena at this location (Figure 12.17) in February 2009. Four samples were analyzed at the Keck Isotope Laboratory, UC-Santa Cruz.

The metalliferous ore deposits of Iran are numerous and widespread but nowhere are they richer or more varied than in the Central Persian Desert (Wertime 1968). "At Anarak-Nakhlak nearly all the minerals of the desert come together in a remarkable and evident juxtaposition; thus this region was one of the earliest homes of metallurgy anywhere in the world" (ibid.: 927). The argentiferous lead deposit at Nakhlak (N 33° 33' 50", E 53° 50' 40"), which have been assayed at silver 715 grams per ton, appears to have been worked since ancient times (Holzer and Ghasemipour 1973). Stos-Gale (2001) published the results of Pb isotope analyses on slags and ores collected from this deposit, the values of which have been extrapolated for use in the present study (Appendix 12.6).

### *Afghanistan*

Referring back for a moment to Figure 12.2, it is plain to see that Afghanistan is a conspicuous "hole" in this dataset that, although not comprehensive, is otherwise reasonably representative of the different regions immediately surrounding the Indus Basin where Harappans might potentially have acquired lead or silver (if extracted from lead). There are five major lead deposits and nearly 100 more documented occurrences and showings of that metal throughout Afghanistan (ESCAP 1995: 30). One of the more important sources in terms of this study is the Asad Qala (Kalai-Assad) deposit (Berthoud *et al.* 1977; Jarrige and Tosi 1981), which is around ten kilometers north of the Helmand Tradition site of Mundigak (Casal 1961). Isotopic assays have been made for a series of lead and silver artifacts from Mundigak and are presented below. Until geologic materials from Asad Qala can be analyzed, those artifacts may serve as proxy samples for that deposit (of course, I am making the assumption that the metal was locally procured).

## Plotting and evaluating the Pb isotope data for South Asian lead deposits

When the 232 Pb isotope determinations comprising the lead deposits database are placed on a bivariate plot of the ratios $^{208}Pb/^{207}Pb$ and $^{207}Pb/^{206}Pb$, the majority (211) of samples cluster into a loose linear pattern (Figure 12.18). Twenty-one samples (from Banejnes, Uchich, Besham and six deposits in South India) are isotopically distant outliers (Figure 12.19) to the main body of lead deposits. Although there is a degree of overlap between many of the individual deposits and ore fields, by and large, most major lead sources are isotopically distinct from one another – especially a when considered at a regional scale. For example, most of the lead deposits of Rajasthan cluster in the lower right area of Figure 12.18. The Ambaji-Sendra belt, which extends from Gujarat into south central Rajasthan, falls toward the middle of the plot. A few remaining deposits in Rajasthan trend toward the upper left. All of the lead deposits in Balochistan, however, plot squarely in the far upper left of the figure. Although samples from sources in the Himalayas and the NWFP fall at several different places across the trend, they mostly plot apart (although there are degrees of overlap in places) from the other deposits. The complex geologic histories and processes that affect the isotopic composition lead occurrences in these regions and cause them to plot as they do is not the subject matter of this book. What is important with regard to this study is that lead ores deriving from the various regions are, to a very large degree, isotopically distinct from one another. Therefore, when a question is posed such as – Did the metal for these lead or silver artifacts come from sources in Rajasthan, Balochistan, the Himalayas or elsewhere? – then providing an answer may very well be possible with reference to this Pb

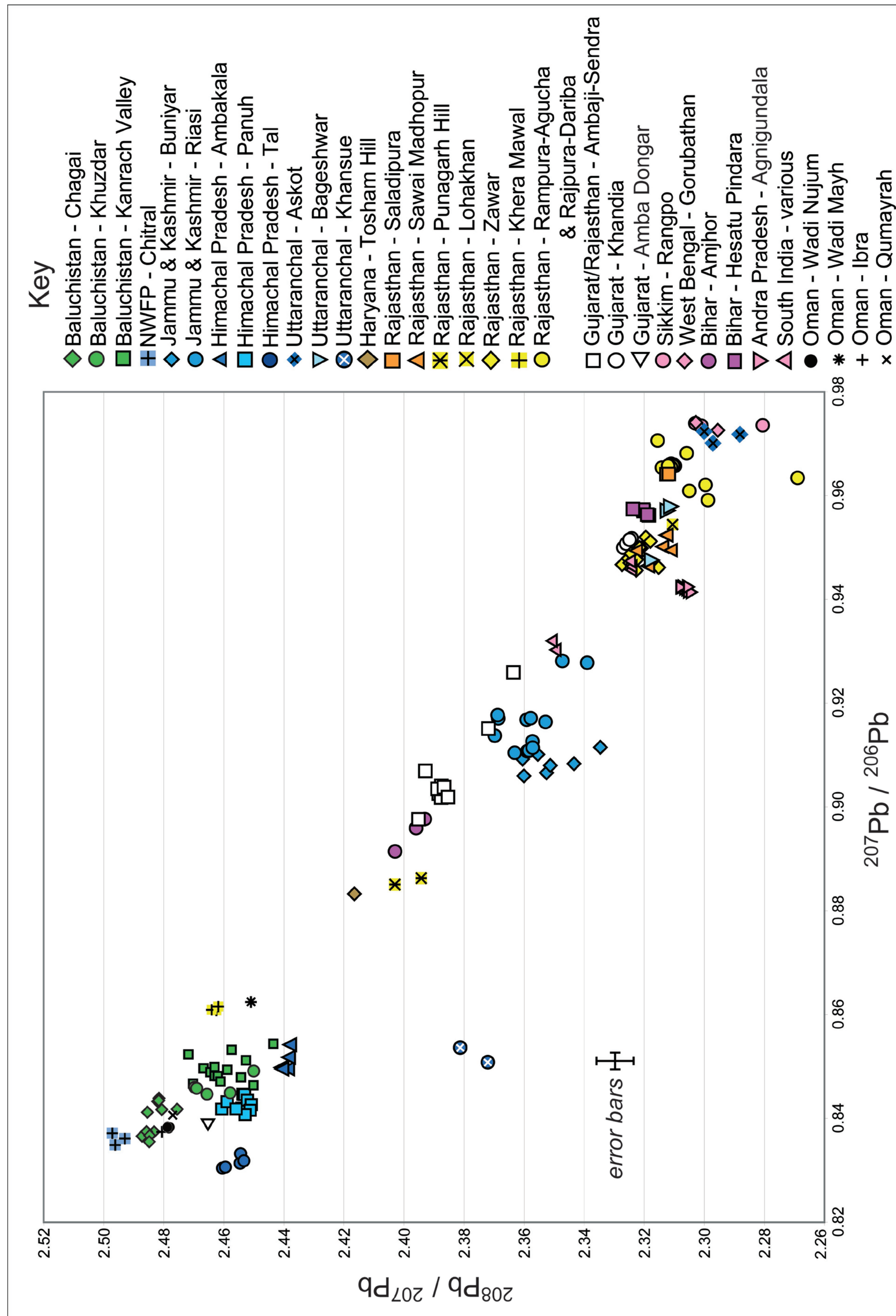



**Figure 12.18** Plot of Pb isotope ratios for galena samples from South Asian and eastern Arabian lead ore deposits. This is the main body of ore deposits. see Fig. 12.19 for outliers.

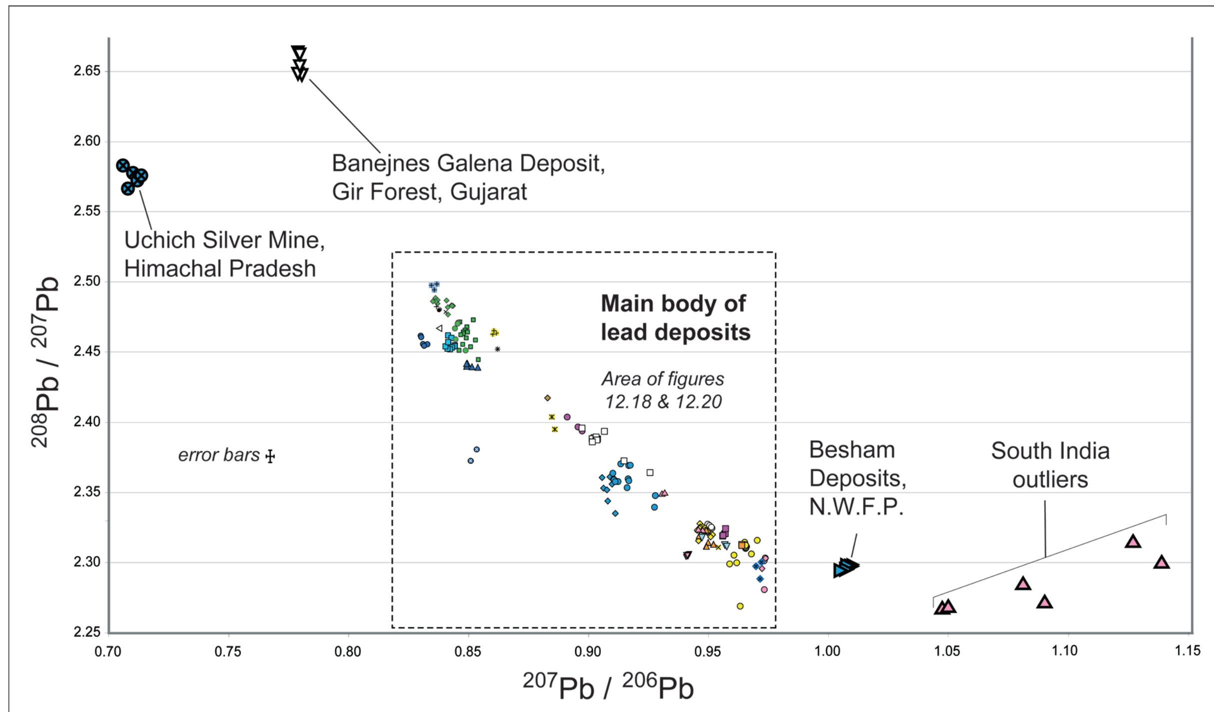



**Figure 12.19** Isotopically outlying South Asian lead ore deposits.

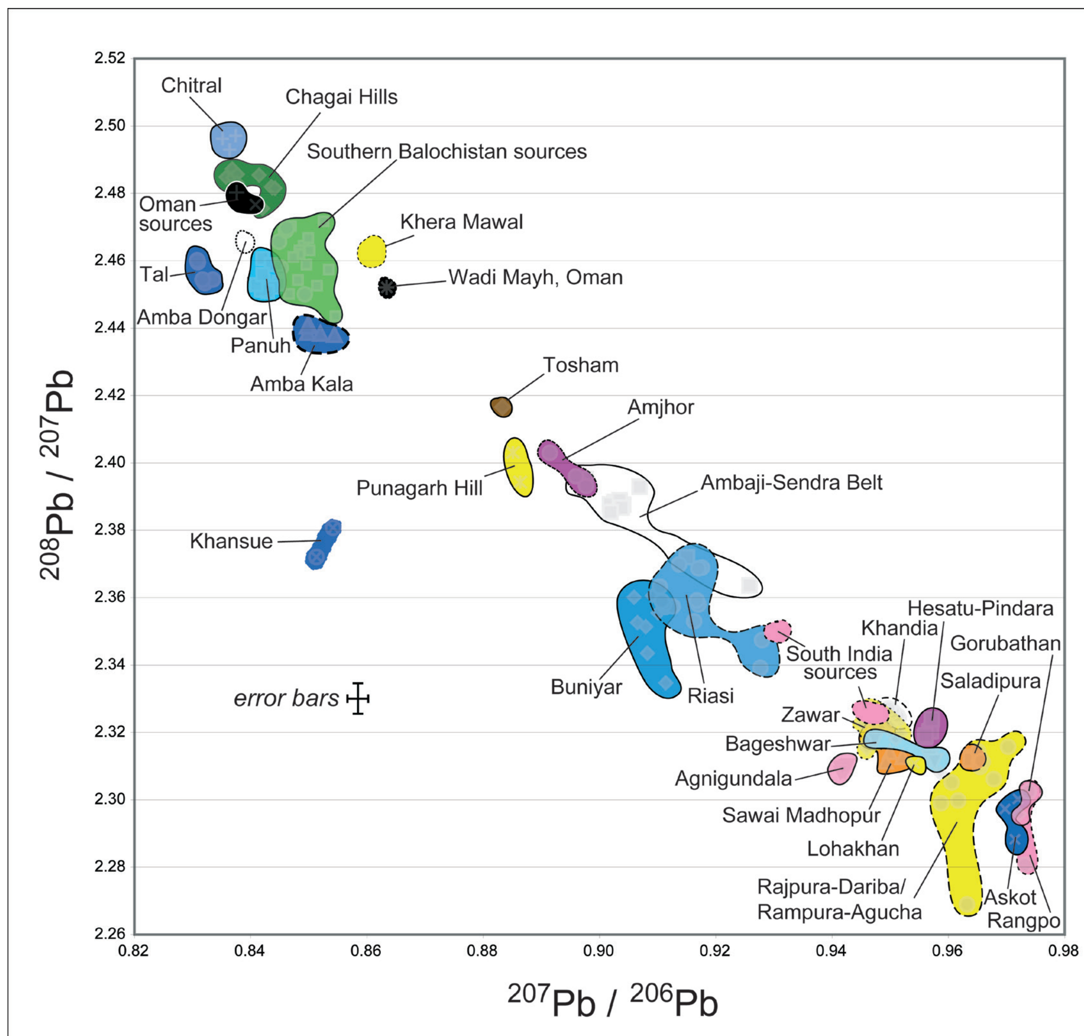



**Figure 12.20** Isotope "fields" of the "main body" of South Asian lead ore deposits.

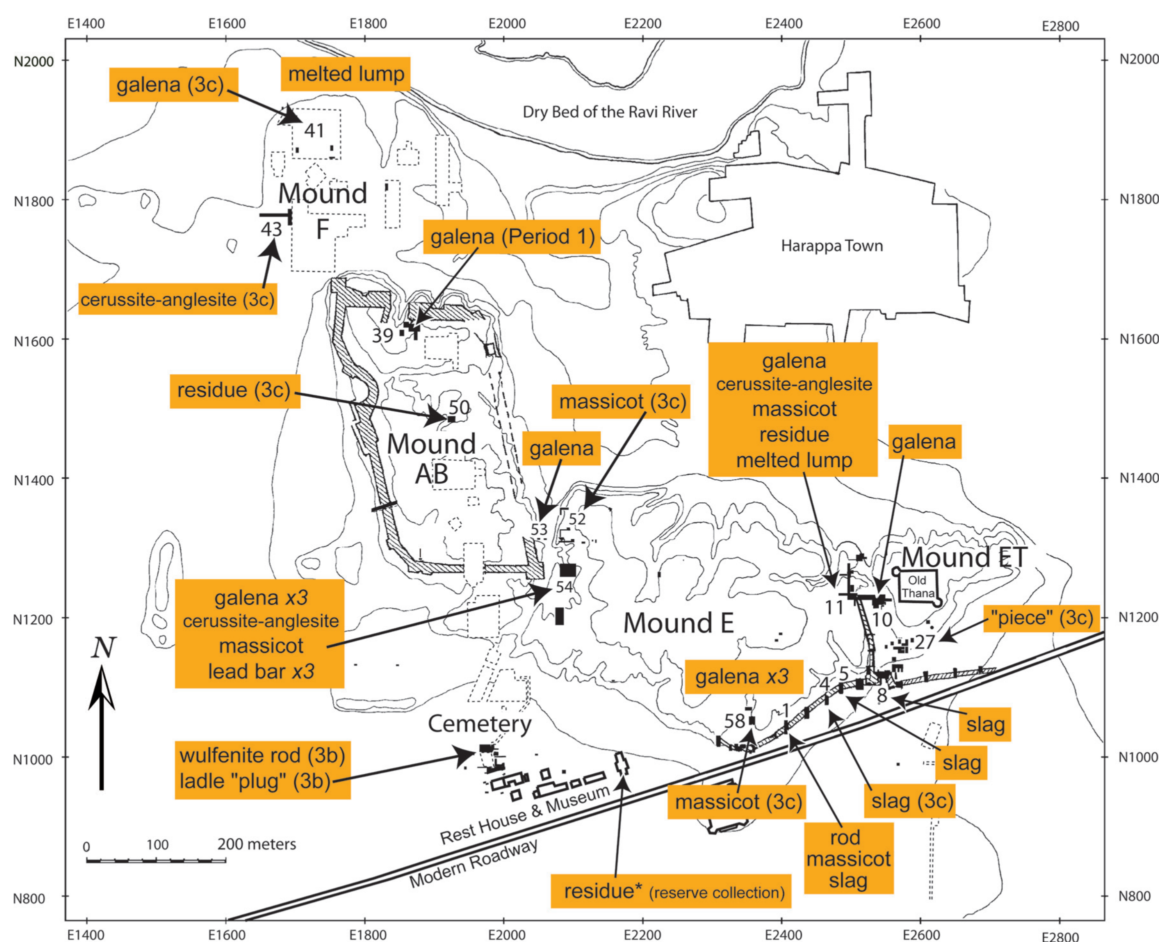



**Figure 12.21** Harappa site plan with numbered trenches and areas where lead ores, objects, slags or residues have been recovered. Dateable artifacts = (period). Others are surface/disturbed. Multiple artifacts = x number.

isotope database. I address these very questions in the upcoming sections of this chapter.

To aid in interpretations of the archaeological Pb isotope data, I have created a new version (Figure 12.20) of the bivariate plot in which the different groups of lead ore occurrences (or "fields") that comprise the main body of geologic samples have been outlined and labeled. The shapes demarcating ore "fields" were drawn by hand and are *not* statistical confidence intervals. They are meant only to be visual guides (it is easier to see individual points plotted against solid shapes versus numerous data points). Individual data points are still visible as lightly superimposed geometric shapes. Crossed bars representing the overall range of analytical error (standard deviation of the mean of repeated measurements of the NIST lead isotope standard) are present on each plot.

## Determining the probable geologic proveniences of lead artifacts from Harappa

Thirty-four "lead" artifacts, in total, have been recovered during HARP excavations and Pb isotope data have been produced for all of them using the EDTA/ICP-MS method. Nineteen are raw lead ores (Appendix 12.2) while the remaining ones are finished items, lead slags, melted lumps and residues (Appendix 12.3). Examples have been found on every mound and in the cemetery area (Figure 12.21). One ore fragment was found in Ravi Phase (Period 1) levels, two finished items were found in Period 3B burial contexts and a total of 10 artifacts (including ores, residues, slags and finished items) come from

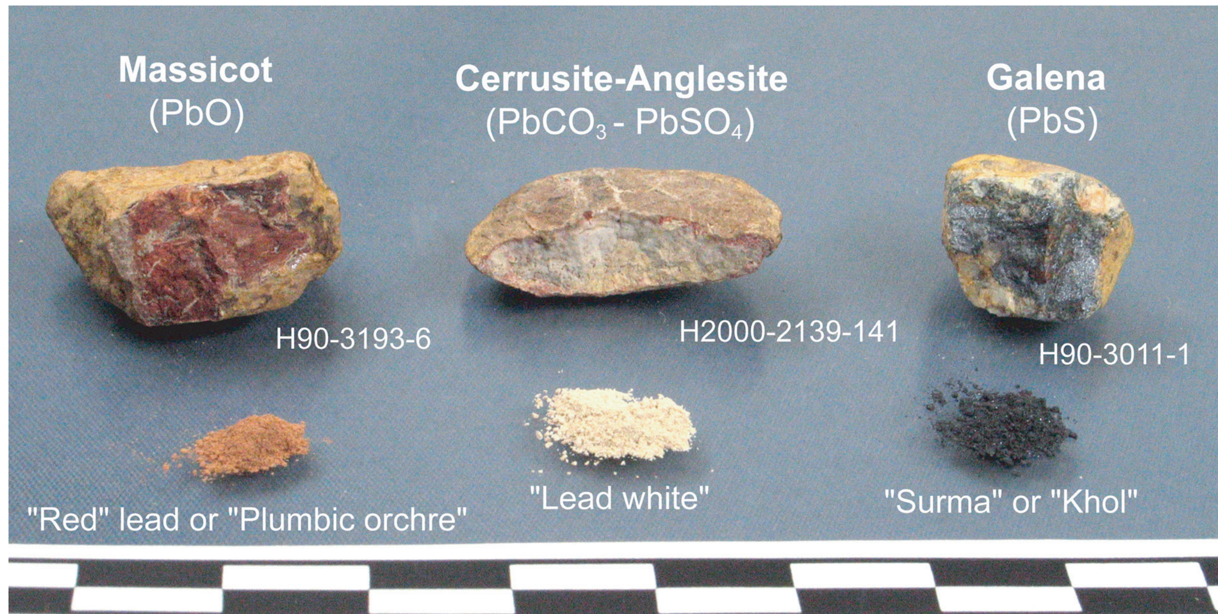



**Figure 12.22** Three varieties of lead ore found at Harappa and pigments derived from them.

KEY
*Galena*
*Cerussite-Anglesite*
*Massicot*

$^{208}$Pb / $^{207}$Pb
$^{207}$Pb / $^{206}$Pb

2.52
2.50
2.48
2.46
2.44
2.42
2.40
2.38
2.36
2.34
2.32
2.30
2.28
2.26

0.82
0.84
0.86
0.88
0.90
0.92
0.94
0.96
0.98

Chitral
Chagai Hills
Southern Balochistan sources
Oman sources
Khera Mawal
Tal
Wadi Mayh, Oman
Amba Dongar
Panuh
Amba Kala
Tosham
Amjhor
Punagarh Hill
Ambaji-Sendra Belt
Khansue
Riasi
Hesatu-Pindara
Khandia
Gorubathan
South India sources
Saladipura
Buniyar
*error bars*
Zawar
Bageshwar
Agnigundala
Sawai Madhopur
Lohakhan
Rajpura-Dariba/
Rampura-Agucha
Askot
Rangpo

**Figure 12.23** Raw lead ore fragments from Harappa plotted against South Asian lead ore fields.

Period 3C levels. The remaining 22 lead artifacts are from surface or disturbed contexts.

***Lead ores***

When performing isotopic or elemental analysis of archaeological metals that have been altered in some way (smelted, forged, cast, alloyed, etc.) there is always the possibility that material from two or more geologic sources may be present in a single artifact. This can potentially lead to the misassignment of an artifact's provenience due to the obscuring of the chemical and/or isotopic characteristics used to match it to a geologic source. When the artifacts under examination are unadulterated metal ores, however, the potential mixing of sources is not an issue. For this reason, raw ore, when it is present at a site, is undoubtedly the best form of archaeological metal to study when attempting artifact-to-source correlation. Lead isotope analysis has been employed successfully in the past to help identify the probable sources of lead ore (galena) fragments excavated at sites in Egypt (Hassan and Hassan 1981) and North America (Farquhar and Fletcher 1984).

As discussed in Chapter 4, XRD analysis has shown that three distinct minerals (Figure 12.22) are represented among the 19 lead ore artifacts at Harappa: massicot (n=5), cerussite-anglesite (n=3) and galena (n=11). Besides being important ores for the metal lead (and, if argentiferous, silver), each are common mineral pigments/cosmetics and go by names like "plumbic ochre" (massicot), "lead white" (cerussite) and "surma" or "kohl" (galena). I discuss this aspect further in the section below where I examine lead residues found in small ceramic and faience bottles, which are possibly cosmetics. Lead minerals are also frequently employed in traditional medicines in South Asia (Murthy 1983) and the Arabian Gulf region (Worthing and Sutherland 1996). It is quite likely that when lead was intentionally brought to Harappa in raw form, it was for one of these uses.

When Pb isotope data for the 19 lead ore fragments from Harappa (Appendix 12.2) are placed on the bivariate plot of the main body of geologic samples (Figure 12.23), they more or less cluster in three areas. Nine artifacts fall within the fields of the Jammu and Kashmir deposits. Although a few of those are isotopically more analogous to either the Riasi samples or the Buniyar samples, most cluster in or near the area where the two sources overlap. Five of the ores plot with samples from deposits in Kanrach Valley and Khuzdar areas of southern Balochistan – sources that have largely indistinguishable Pb isotope characteristics. Here is an instance where having useable $^{204}$Pb measurements (and/or even more accurate $^{208}$Pb, $^{207}$Pb and $^{206}$Pb data) might help to resolve these two sources. On the other hand, it might not. Although the two areas of lead mineralization lie around 180 km apart, both belong to a zone in Jurassic sediments along the western margin of the Indian Plate known as the "Las Bela-Khuzdar metallogenic province" (Jankovic 1986: 1). For now, the two sources have been grouped into one "field" that represents the region of southern Balochistan. The source association of the remaining five ore fragments is more ambiguous. Although two are near geologic samples from the Amba Kala deposit in Himachal Pradesh, all five fall in a blank gap on the lead deposits plot. However, because the artifacts are unadulterated lead minerals, we can be certain that a lead source (or sources) physically exists somewhere with these precise isotopic characteristics. It just has not yet been located, sampled and included in the database.

Interestingly, the nine ores that appear to be from the Jammu and Kashmir sources are all galena fragments. The other two galena artifacts that plot in the "ambiguous" area. The only three examples of cerussite-anglesite from Harappa all plot closely together with the samples from southern Balochistan sources. It is not presently possible to isotopically differentiate lead occurrences in the

Khuzdar area from those in the Kanrach Valley and the mineral could have come from deposits in either area. Cerussite has been reported to occur in "small quantities" in the Las Bela district (Gazetteer of Las Bela 1907: 119) and is found in the oxidation zone of the deposit at Gunga (Jankovic 1986: 4) in the Khuzdar district. The "chief ore" at Shekran is cerussite (Heron and Crookshank 1954: 93) and fragments the mineral have been recovered during both previous (Hargreaves 1929: 33) and current (Ute Franke-Vogt personal communication 2005) excavations at the prehistoric site of Sohr Damb/Nal, which is around 15 to 25 km west of the Khuzdar deposits.

Two of the fragments of massicot – a mineral that likewise forms in the oxidation zones of lead deposits, also appear to come from southern Balochistan sources. The three other examples of that mineral plot with galena fragments in the "ambiguous" region.

#### *"Finished" lead artifacts*

Six "finished" lead artifacts have been recovered at Harappa (Figure 12.24). These include a rivet or plug used to repair a shell ladle (Dales and Kenoyer 1989a: Fig. 58), several small rectangular "bars" one of which (H2000/2174-321) appears to be inscribed, a corroded tubular "rod" fragment and a tiny squarish lead "piece." All of them appear to be composed of entirely of lead metal. As this study now shifts from raw ores to artifacts that have been manipulated in various ways, it is worth emphasizing again that such artifacts, be they "finished" items, slags or residues, might potentially possess Pb isotope characteristics that reflect the mixing of lead from multiple geologic sources. When an artifact is composed of metal from only two sources, its measured isotopic values will plot somewhere along a *mixing line* between them (Klein *et al*. 2004: 470). If the end members of a mixing line are well known and no other deposits are believed to exist that have isotopic values intermediate to them, then a case can be made that artifacts plotting along that line contain metal from both sources (ibid.). However, if other geologic deposits exist between the end members of a potential mixing line, then those same artifacts could be misassigned to them or, alternately, if an intermediate deposit is unknown then an artifact derived from it could be misinterpreted as being composed of a mix of materials from the two end member sources. The situation is further complicated when materials from more than two deposits are used to fashion an artifact or when lead derived from different types of metals are mixed (for instance if copper containing trace lead is alloyed to silver extracted from a lead deposit). In short, when examining any type of artifact other than a raw ore, the possibility *always* exists that measured isotopic values may be a reflection of something other than the actual isotopic characteristics of single geologic source. This is a fact that must be kept in mind when interpreting data of this kind, most especially assays of "finished" artifacts.

When the Pb isotope determinations (Appendix 12.3) for the six "finished" artifacts are placed on the bivariate plot (Figure 12.25), they are distributed among some of the same areas where the lead ores previously clustered. The lead composing two of the bars (including the inscribed one) appears to have been derived from sources in southern Balochistan (although one bar plots at the point where the isotopic values of that source region begin to overlap with values for samples from the Panuh deposit of Himachal Pradesh). The lead used to make the ladle plug and the rod falls into the same general "ambiguous" area that several of the lead ores previously fell. Also plotting in this same general area but directly adjacent to the single data point for galena from the Wadi Mayh area of Oman is the remaining bar and the small lead "piece." These, if real, are interesting and important source associations. However, caution in the interpretation of these data is advised as Wadi Mayh is represented by only one sample and the isotopic characteristics of these




**Figure 12.24** "Finished" lead artifacts from Harappa.

2.52
2.50
2.48
2.46
2.44
2.42
2.40
2.38
2.36
2.34
2.32
2.30
2.28
2.26
$^{208}Pb$ / $^{207}Pb$
Chitral
Chagai Hills
H2000-2174-321
Southern Balochistan sources
Oman sources
Khera Mawal
Wadi Mayh, Oman
Tal
H94-4891-214
Panuh
H2000-2102-1555
H2000-2226-50
H93-3506-43
H88-446-04
Amba Kala
Tosham
Amjhor
Punagarh Hill
Ambaji-Sendra Belt
Khansue
Riasi
Hesatu-Pindara
Khandia
Gorubathan
South India sources
error bars
Buniyar
Saladipura
Zawar
Bageshwar
Agnigundala
Sawai Madhopur
Lohakhan
Rajpura-Dariba/ Rampura-Agucha
Askot
Rangpo
0.82
0.84
0.86
0.88
0.90
0.92
0.94
0.96
0.98
$^{207}Pb$ / $^{206}Pb$

**Figure 12.25** "Finished" lead artifacts from Harappa plotted against South Asian lead ore fields.

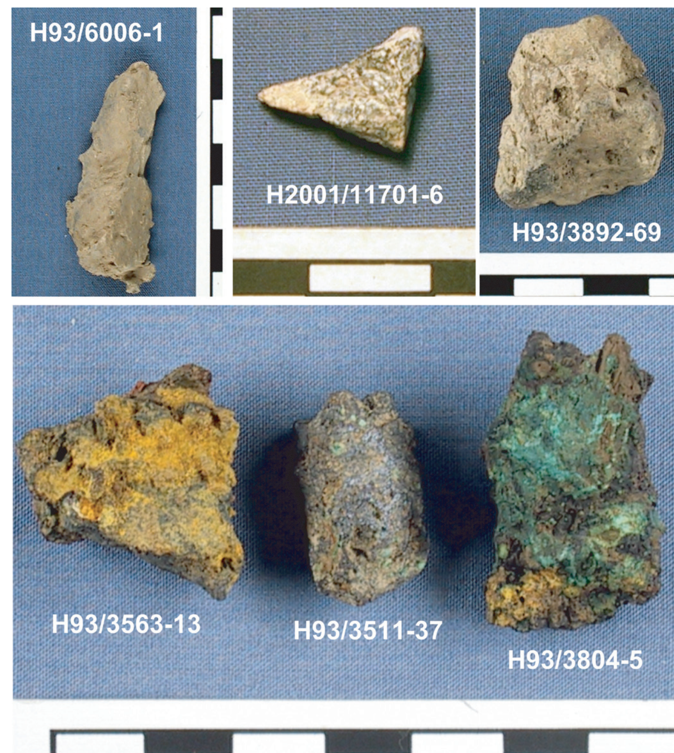



**Figure 12.26** Lead slags and melted lead lumps from Harappa.

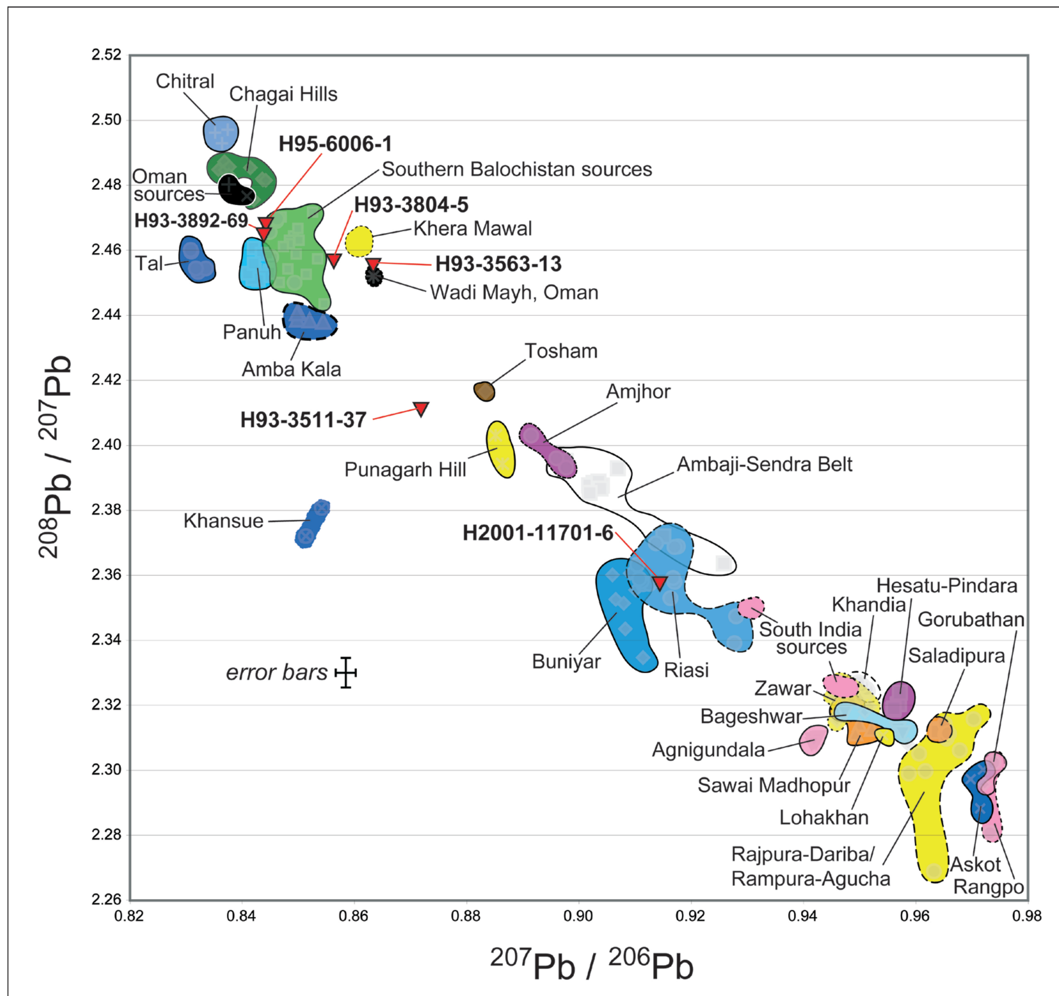



**Figure 12.27** Lead slags and melted lead lumps from Harappa plotted against South Asian lead ore fields.

artifacts could be the result of source mixing.

***Lead slags and lumps***

Isotopic assays were made of six metallurgical craft indicators (Figure 12.26) from Harappa composed of or containing significant amounts of lead. Heather Miller conducted (1994a, 1994b, 1999) a series of surface and subsurface surveys of the site in an effort to locate areas where different types of craft activities were conducted. It was on the southern slope of Mound E that she encountered the heaviest concentration of metallurgical craft indicators (metal or metalliferous scraps, slags, prills, crucible and kiln fragments) (Miller 1999: 414-419). Most of these were related to copper production but a few of the slags quite clearly had a significant lead component (i.e. yellow oxidized patches and/or visible lead prills). A yellow patch on one slag sample (H93/3804-5) that Miller had analyzed using XRD and XRF (X-ray fluorescence) was shown to contain, among other things, lead bromide and massicot (Heather Miller *personal communication* 2003). A few non-descript melted lumps of lead have also been recovered during surveys and excavations at Harappa.

When the Pb isotope determinations (Appendix 12.3) for the lead-rich metallurgical slags and melted lead lumps are placed on the bivariate plot (Figure 12.27), they again cluster in the same three general areas as the ores and finished artifacts did. One of the lumps (H93/6006-1) and a frothy slag with lead prills (H93/3892-69) fall closely together on the upper left margin of the southern Balochistan cluster, while another slag (H93/3804-5) plots on the right margin of that cluster. A third slag (H93/3563-23) falls directly adjacent to the Wadi Mayh sample and a fourth (H93/3511-37) lie in the "ambiguous area," away any of the sources in the database. The other lead lump (H2001/11701-6) is isotopically analogous to deposits in the Jammu and Kashmir region.

The possibility (even the probability) that these artifacts contain lead from multiple geologic sources should be kept closely in mind when interpreting this data. Copper oxidation (identified by XRD as *atacamite* [$Cu_2Cl(OH)_3$] – Heather Miller *personal communication* 2003) is, in addition to the previously mentioned patch of lead oxidation, quite clearly evident on slag H93/3804-5 (Figure 12.16 far right). Although most of the lead measured on this sample would have been extracted from the lead-rich portion of the artifact, it is still unknown whether or not that was representative of more than one geologic source or how any trace amounts of lead in the copper-rich portion may have affected the results. Some of these artifacts, therefore, may fall upon a yet to be defined mixing line. For instance, a mixture of lead from a source in southern Balochistan with that from one in the Jammu and Kashmir region would probably have isotopic values much like those exhibited by slag H93/3511-37. The possibility that this occurred is evaluated again later in this chapter when isotopic data for all lead artifacts are examined together.

***Lead residues***

In this section, I examine the compositions and probable geologic proveniences of lead residues found in small bottles and/or in other forms at Harappa. Lead minerals were used in many parts of the ancient world to produce pigments for both painting and self-adornment (Nriagu 1983; Rapp 2002: 210-211). Archaeological lead residues found at Indus sites are very likely the remains of substances that Harappans used as cosmetics. "Surma" (or "kohl" as it is known in Arabia and across the Near East) is a silvery-black eye salve/cosmetic that is ostensibly made using the mineral antimony and, thus, the thin, elongated objects found at Indus sites that were probably cosmetic applicators are often dubbed "antimony rods. " In reality, this cosmetic/salve usually contains the lead mineral galena (see my analysis of modern surma in Appendix 12.7 as well as studies by al-Hazzaa and Krahn 1995; Hardy *et al*. 1998; Parry and Eaton 1991; and Vaishnav 2001). Surma/kohl, other lead-

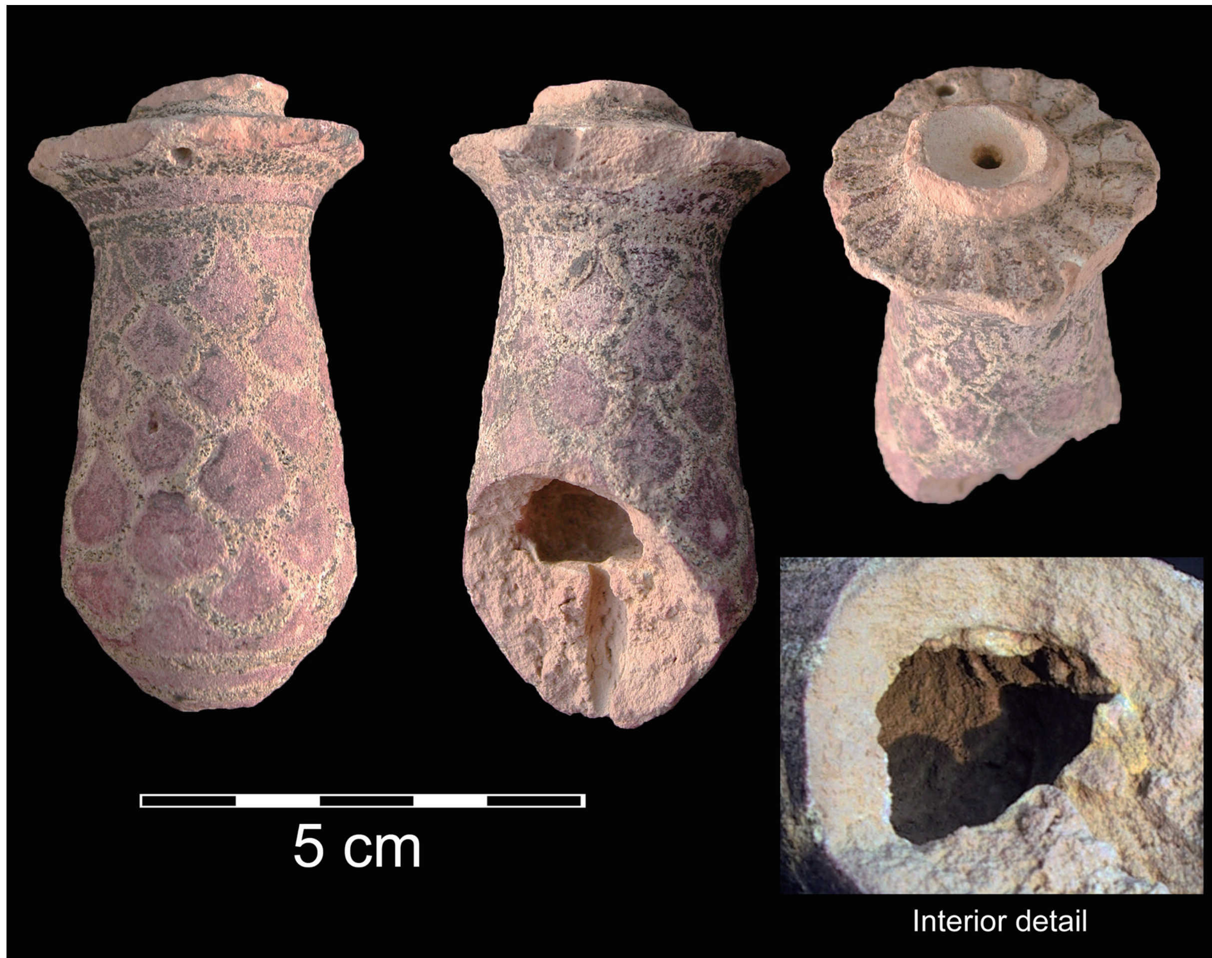



**Figure 12.28** A small faience bottle (H98/8158-26) with patches of lead residue adhering to its interior (see inset detail).

based cosmetics (such as "lead white" made from powdered cerussite) and the vessels designed to hold them ("kohl" pots, jars or tubes made of a wide range of materials) are very well known from ancient Egypt and the Near East (Lucas and Harris 1999; Ungár *et al*. 2002; Walter *et al*. 1999). Although it is commonly assumed that the many miniature ceramic, faience, stone or metal vessels found at Harappa and Mohenjo-daro held, among others things, similar kinds of cosmetics, documentation of these substances has been limited. A small alabaster pot at Mohenjo-daro was found to contain galena (Mackay 1938: 665) and a white substance in a small beaker at Harappa was identified as cerussite (Vats 1940: 312).

Numerous tiny vessels and vessel fragments have been recovered during HARP excavations. The contents of two contained residues that were sampled for this study. The first (Figure 12.28) is from a small faience bottle with a very constricted opening (H98/8158-26). The base of the bottle was broken and patches of a thin yellow residue could be seen on its interior. The second is from a small bottle fragment (H87/539-80) that still had a thick yellow and white residue adhering to its interior (Figure 12.29). XRD analysis of that residue indicated that it was composed of cerussite and another phase that, although I have not yet been able to conclusively identify it, has a major peak that is reminiscent of a copper mineral of some kind. Although this residue is likely the remains of a cerussite-based cosmetic like "lead white", it is not impossible that the bottle may have originally held a galena-based surma that has since oxidized as cerussite – a phenomenon documented in a study of kohl from Roman-era Palestine (Grüner 2002: 80).

I also had the opportunity to examine small vessels from past excavations at Harappa that were

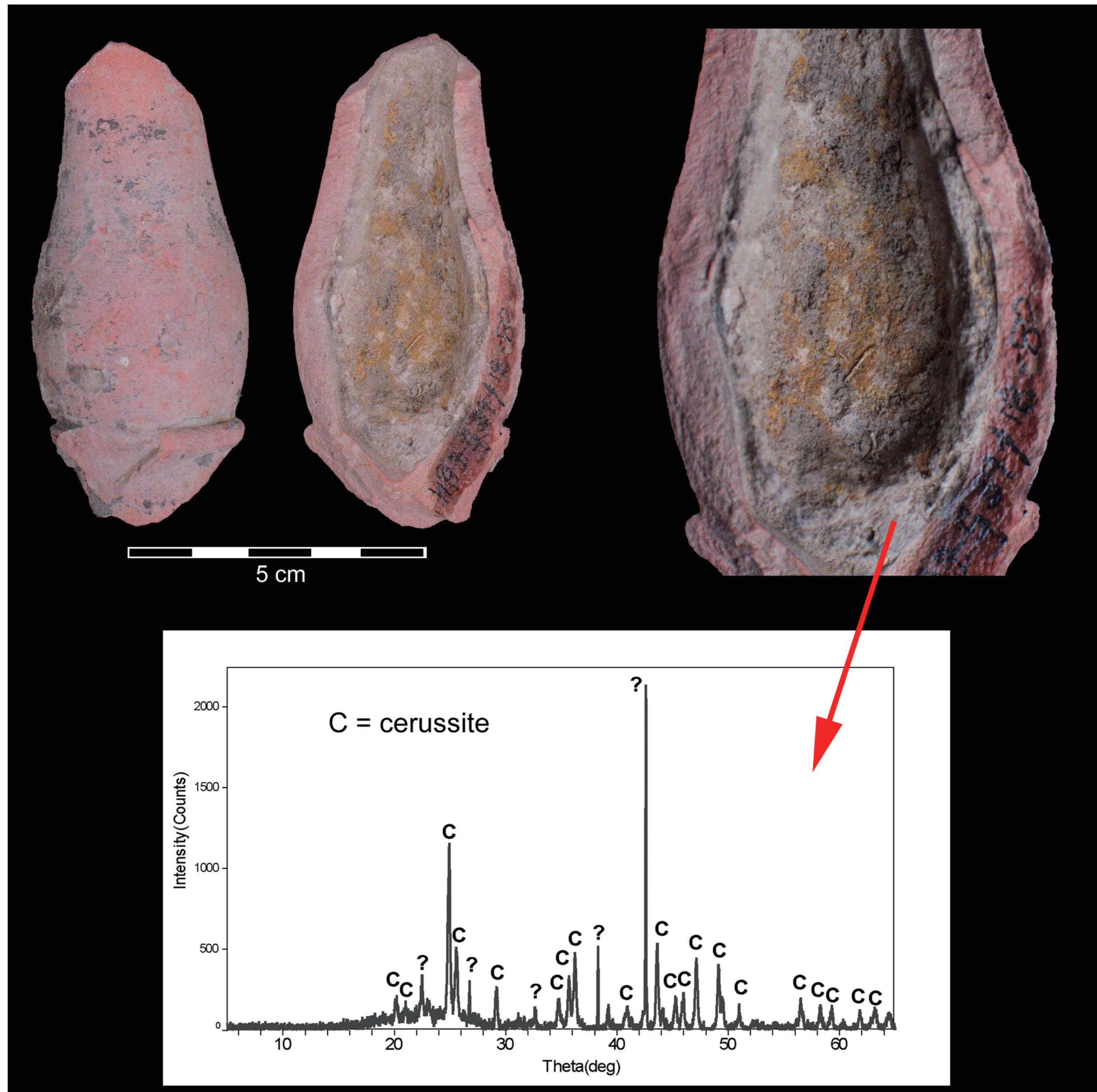



**Figure 12.29** A small ceramic bottle fragment (H87/539-80) with a thick layer of residue in its interior that was identified by XRD as mainly being composed of cerussite.

stored in the reserve collection of the site museum. Most contained no visible evidence of any residue that may have provided clues as to what they once held. However, the rims or interiors of six small bottles (Figure 12.30) were darkened as if they had contained a black substance such as surma. Each bottle was sampled using the EDTA technique to see if enough (or if any) lead was present on it for isotopic analysis. After the solutions were returned to Madison and assayed, it was determined that only one had contained any lead at all – a small jar from Vats' excavations (1940) identified by the number *3906* (Figure 12.30 far right). If the other vessels had once held a black cosmetic, it was probably made from organic substances such as "lamp black mixed with fat" as Ernest Mackay had once proposed (1938: 665), rather than a lead mineral.

One final, particularly interesting residue from the HARP excavations was originally thought to be a metal "rod" (Figure 12.31 – artifact H88/197-1). It was recovered in the grave of an adult woman in a disturbed (in antiquity) cemetery area burial




**Figure 12.30** Six tiny ceramic vessels from Harappa Museum's Reserve Collection. Only the one on the far right (# 3906) was found to have once contained a lead substance.




**Figure 12.31** Artifact H88/197-1, which was originally described as a lead “rod” but is now believed to be a solidified lead residue.

dating to Period 3B (Figure 12.32 A). The “rod”, which is somewhat fragile and not as heavy as would normally be expected of an item made of metal, was excavated already in a fragmentary condition (Figure 12.32 B). The material that it is composed of was initially classified by Dales and Kenoyer (1989: 91) as “lead/orpiment” because of its bright orange-yellow (very orpiment-like) oxidized exterior. When I first examined this artifact in December of 2003, I noticed that a small amount of powder had accumulated in the bag holding it. This was collected and analyzed using XRD. The resulting pattern (Figure 12.32 C) indicated that the “rod” (or at least the powder coming off of it) was composed primarily of *wulfenite*

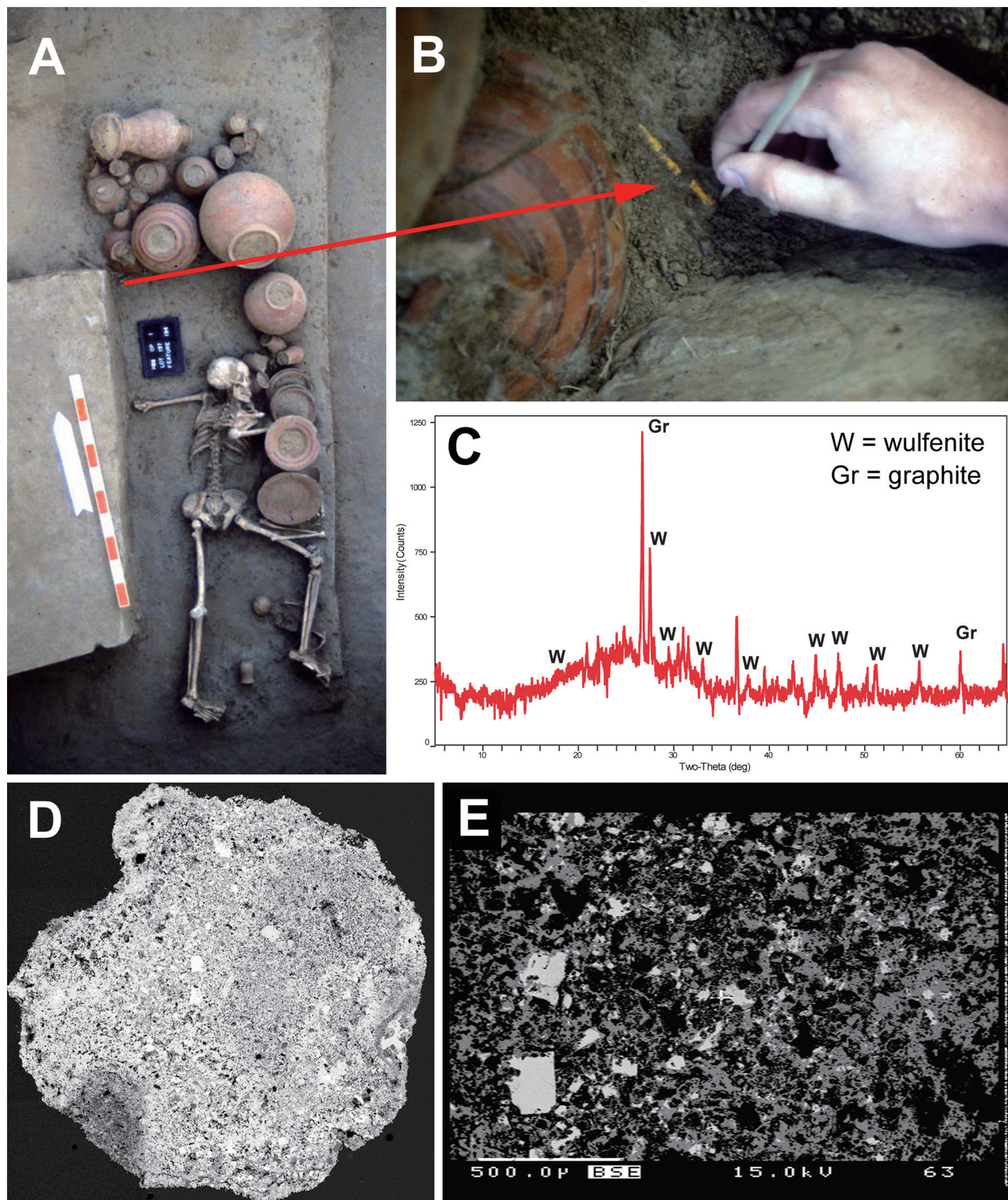



**Figure 12.32** Excavation and analysis of artifact H88/197-1. **[A]** The artifact was found within Feature 194a – a Period 3B burial. **[B]** Excavation of the "rod" in two pieces. **[C]** XRD revealed that it was composed of wulfenite (lead molybdate) and graphite. **[D]** BSE image of the "rod" in section. **[E]** Detail of the artifacts non-metallic, heterogeneous matrix with galena crystals imbedded within it.

(peaks identified with a W on the XRD scan) and *graphite* (identified with a Gr). Wulfenite – lead molybdate ($PbMoO_4$), is another mineral found in the oxidation zones of lead deposits and sometimes has an orange-yellow appearance (Read 1979: 466).

Graphite is, of course, pure native carbon. It crossed my mind that the carbon in the artifact, although identified as graphite, may actually be charcoal, "bone black", or "lamp black" – carbonaceous substances used as black cosmetic pigments in South Asia (O.P.

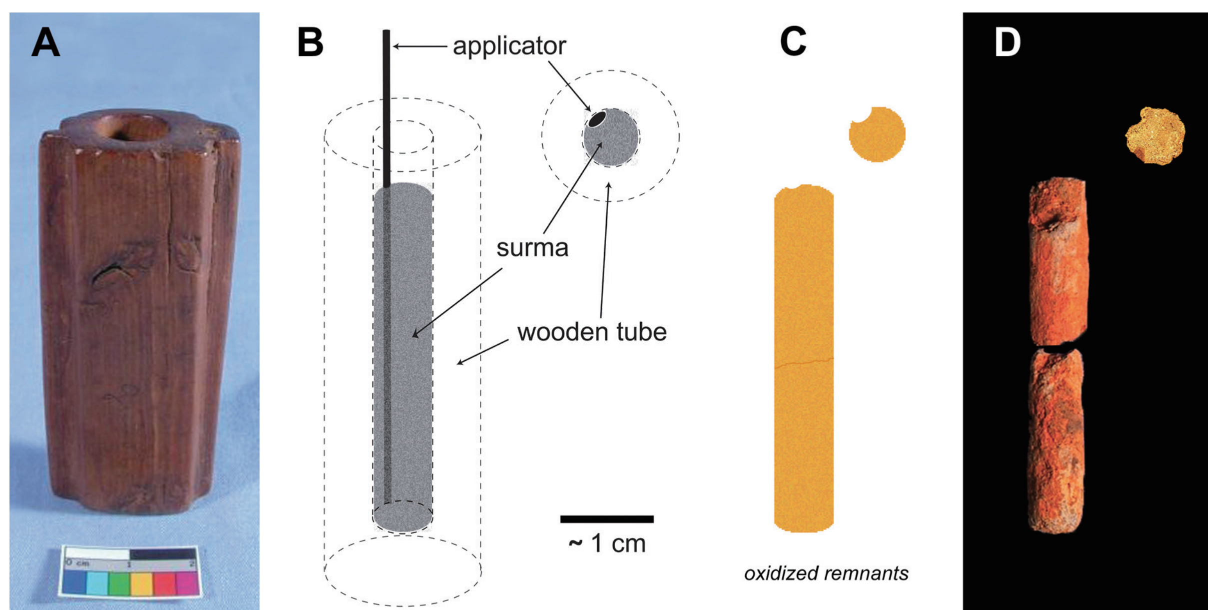



**Figure 12.33** **[A]** Wooden "kohl tube" from Gurob, Egypt, Image used courtesy of the Petrie Museum of Egyptian Archaeology, University College London. **[B]** Reconstruction of a wooden "surma tube" with a applicator set into the powered lead-based cosmetic held within it. **[C]** Reconstruction of the oxidized remains of the surma after the tube and applicator. **[D]** Photograph and BSE scan section of artifact H88/197-1 for comparison.

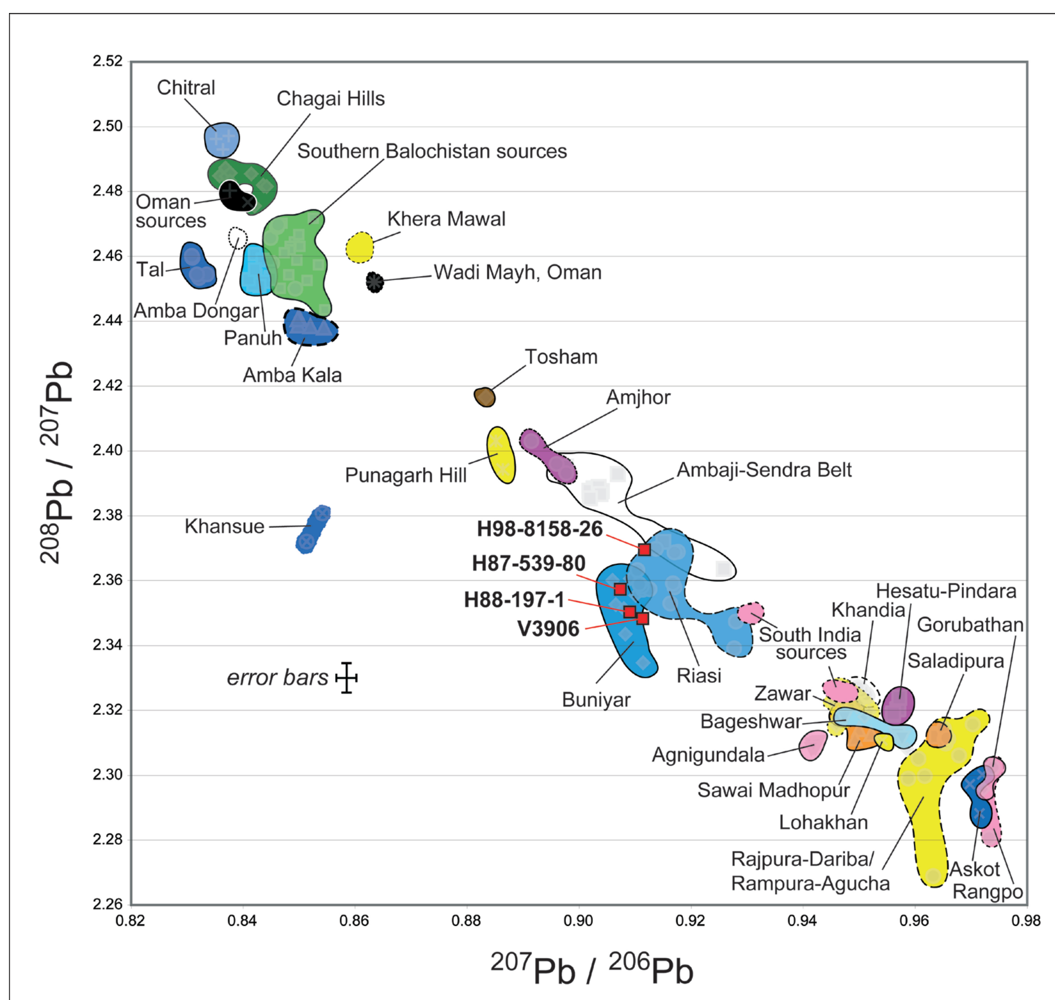



**Figure 12.34** Lead residues from Harappa plotted against South Asian lead ore fields.

Agrawal 1999: 193-194). However, carbons such as these are amorphous and would not have registered peaks on the XRD scan.

A small portion of one of the broken ends of the "rod" was removed for further study using EMPA. The BSE image of this piece in section (Figure 12.32 D) revealed that it is not composed of solid metal (hence the artifact's light weight) but rather is a composite of several granular substances of varying consistencies that have been mixed together. EDS scans indicated that one of these substances was lead sulphide (galena). Cubic crystals of galena can be clearly seen in the artifact's matrix (Figure 12.32 E).

I believe that this artifact, rather than being the remnants of a rather fragile "rod", may instead be the solidified residue of surma powder that was once held in the tube-shaped interior of a container made of a perishable material like shisham wood or bamboo. Cylindrical "kohl tubes" made of wood or reed are well known from ancient Egypt. The one shown in Figure 12.33 A was excavated by Flinders Petrie at New Kingdom site of Gurob (Thomas 1981: 63 [UC 7891]). There is a groove running down the lengths of the Harappan "rod"/residue fragments (visible in section on the upper left of the BSE scan on Figure 12.32 D) that may be the place where a thin cosmetic applicator (probably also perishable) was set into the powder. Over time, the wooden tube and applicator (Figure 12.33 B) disintegrated leaving only the lead-based powder, which consolidated but cracked as it oxidized, in the tubular rod-like shape of the container's interior with a small groove running down its length (Figure 12.33 C). I believe this reconstruction best accounts for the features exhibited by this artifact (Figure 12.33 D).

The Pb isotope compositions of the four residues analyzed (Appendix 12.3) indicate (Figure 12.34) that the lead in each of them was probably acquired from sources in the Jammu and Kashmir region. It should be noted, however, that although the "rod"/ residue (H88/197-1) that contained wulfenite would seem to have come from one of the Buniyar sources, this mineral has not as yet been reported in that area or, for that matter, anywhere in Jammu or Kashmir. Even so, wulfenite can form due to lead-molybdenum impurities in *sphalerite* (Guilbert and Parks 1986: 809) – a zinc mineral which is found throughout the zone of sulphide mineralization at Buniyar (Sharma and Sachan 1998). Moreover, mineralization there is thought to perhaps be epigenetically related to intrusive granitoid plutons in the vicinity (Kaul 1981), which could have easily contributed the molybdenum impurities that oxidized with lead as wulfenite ($PbMoO_4$). Also significant with regard to the "rod"/ residue, is the fact that graphite associated with igneous rocks is abundant in the vicinity of Buniyar (Mehta 1957) as well as nearby the unassayed lead deposits of the Doda district (Gupta and Guha 1988).

Although more geologic research remains to be done in order to fully understand the nature of lead deposits in Jammu and Kashmir, it is of interest to note here that the southernmost occurrences in the Buniyar area (those nearest to the igneous intrusives) are found around the village of "Surmawali" (Raina 1977), which is presumably so named (as many villages in the vicinity of lead deposits seem to be, e.g. *Surmai* village in the Khuzdar district of Balochistan) because the raw material for surma is obtained at this location.

### Isotopic assays of lead and silver artifacts from eight other prehistoric sites

In this section, I present the results of a series of Pb isotope analyses made on various kinds of lead artifacts from the prehistoric sites of Shahr-i-Sokhta, Mundigak, Mehrgarh, Gola Dhoro, Nausharo and Mohenjo-daro (Appendix 12.4). Isotopic assays of silver artifacts from Mundigak, Nagwada, Gola Dhoro, Mohenjo-daro and Allahdino (Appendix 12.5) have been made and are also evaluated in relation to the lead deposits database. Although these eight ancient settlements are not the focus of this study,

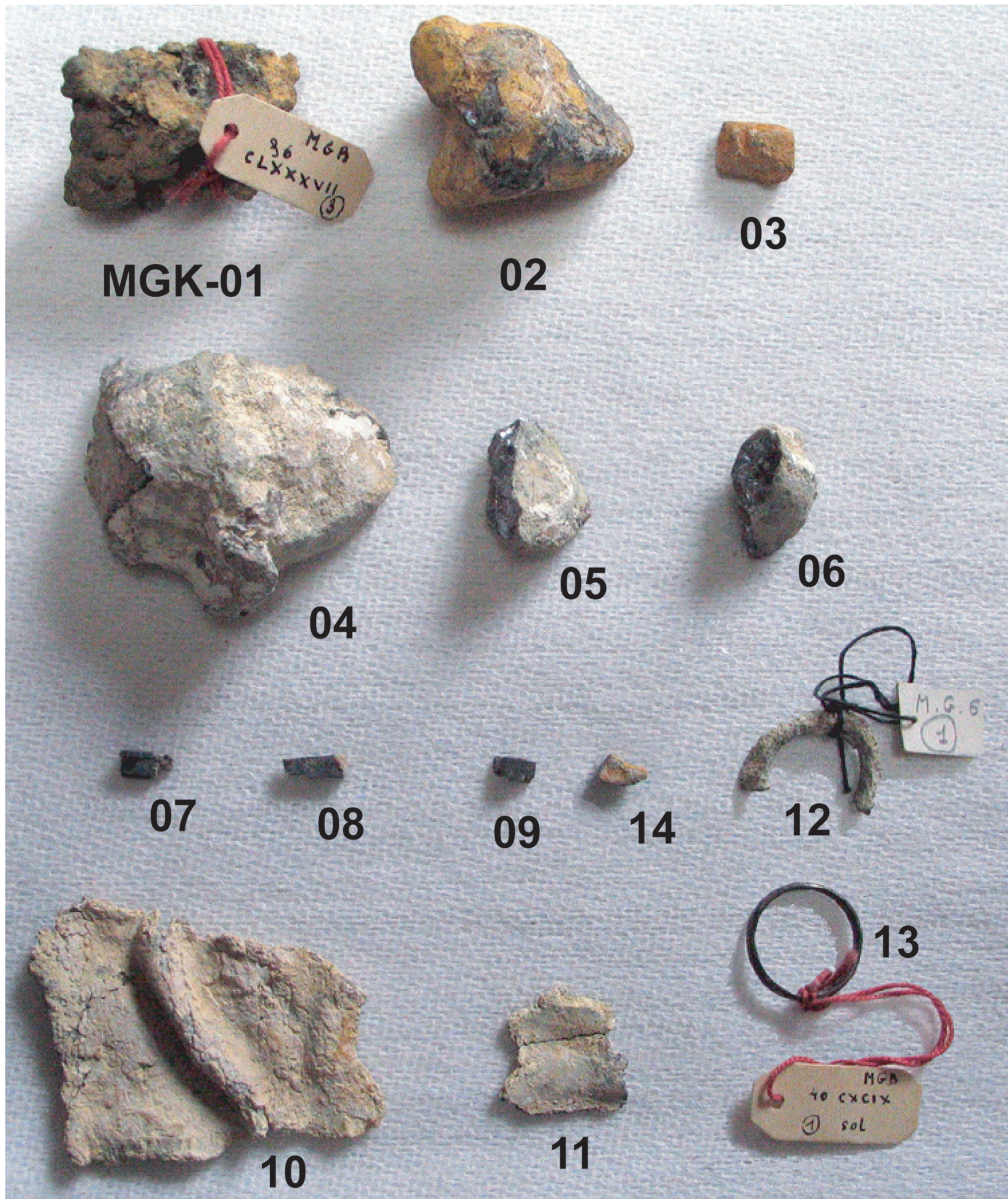



**Figure 12.35** Lead and silver artifacts from the site of Mundigak, Afghanistan.

incorporating data on artifacts from them into it, 1) allows the lead acquisition networks that residents of Harappa were involved in to be viewed from a perspective that is more holistic, 2) provides an indication (by proxy) of what the isotopic character of lead deposits in certain regions (southern Afghanistan and eastern Iran) not represented in the database *may* be like and 3) permits a material type (silver) to be examined that was widely used by Indus Civilization peoples, but for which examples from Harappa are not available for analysis.

*The sites and artifacts*

Lead artifacts from six prehistoric sites were sampled and analyzed using the EDTA/ICP-MS technique. Data for and descriptions of individual

**Figure 12.36** **[A]** Galena fragment and **[B]** copper surma bottle from Mohenjo-Daro.

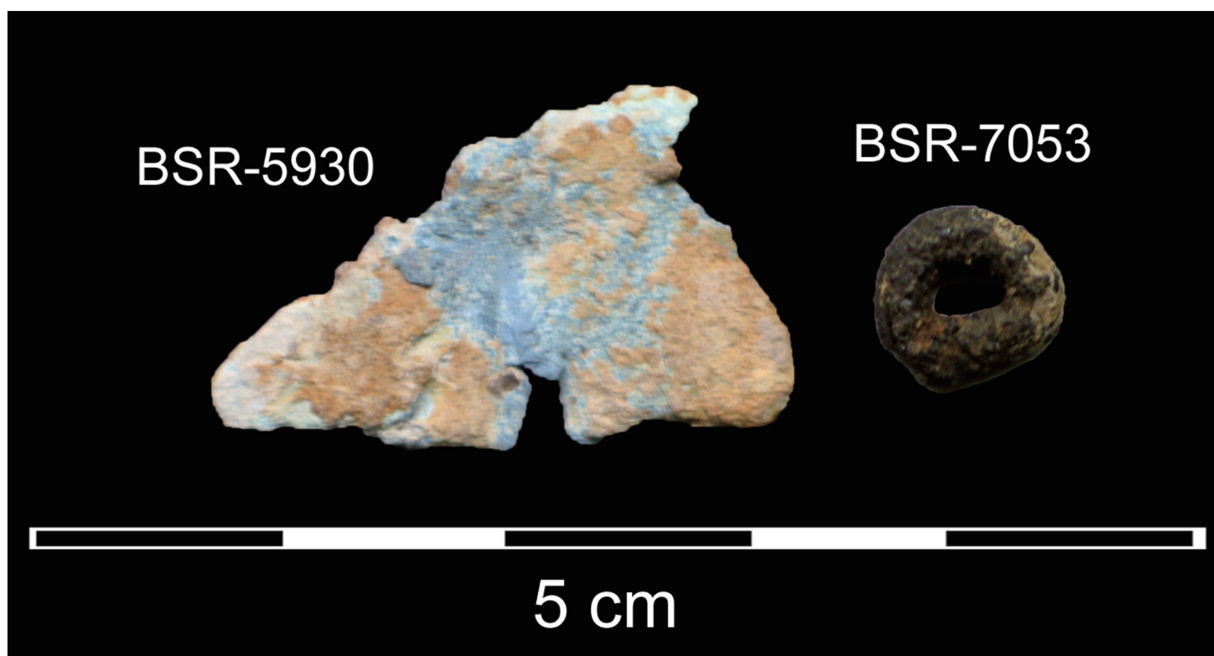
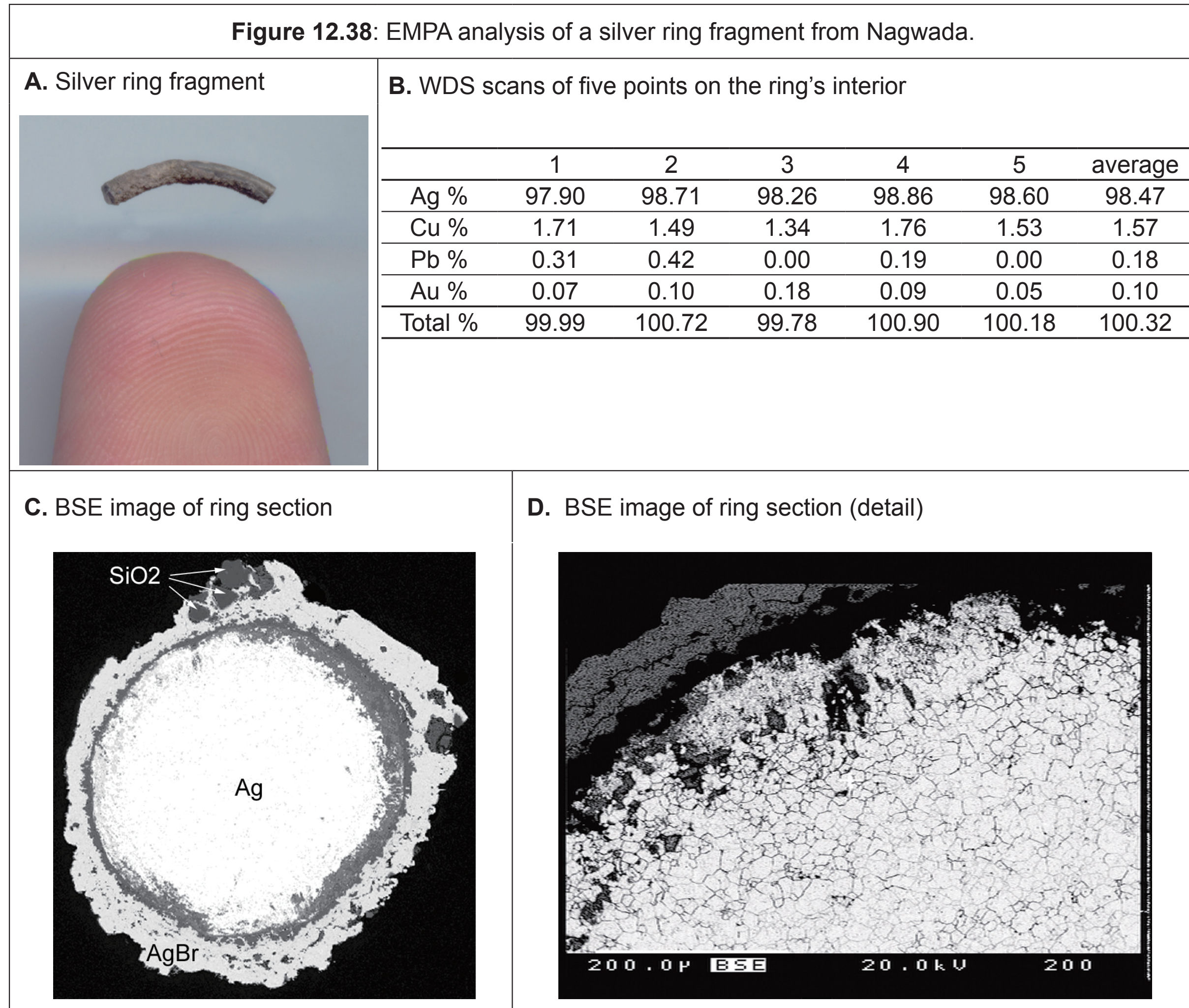



**Figure 12.37** A flattened lead lump (BSR-5930) and a silver ring from (BSR-7053) from the site of Gola Dhoro, Gujarat.




| | 1 | 2 | 3 | 4 | 5 | average |
|---|---|---|---|---|---|---|
| Ag % | 97.90 | 98.71 | 98.26 | 98.86 | 98.60 | 98.47 |
| Cu % | 1.71 | 1.49 | 1.34 | 1.76 | 1.53 | 1.57 |
| Pb % | 0.31 | 0.42 | 0.00 | 0.19 | 0.00 | 0.18 |
| Au % | 0.07 | 0.10 | 0.18 | 0.09 | 0.05 | 0.10 |
| Total % | 99.99 | 100.72 | 99.78 | 100.90 | 100.18 | 100.32 |

**Figure 12.38**: EMPA analysis of a silver ring fragment from Nagwada.

artifacts can be found in Appendix 12.4. All site locations are noted on figures 12.2 and 12.3.

Dr. Massimo Vidale graciously provided access to two galena samples from the Helmand Civilization urban center of Shahr-i-Sokhta in the Seistan Basin of eastern Iran (Tosi 1982). As the majority of metallurgical finds from this site date to the mid-third millennium BC (ca. 2700 to 2500 BC) levels there (M. Tosi cited in Hauptmann 2003: 198), it can probably be assumed that these archaeological ores, which are part of a larger collection of mostly copper artifacts and manufacturing debris presently under examination from that site (Giardino *et al. in preparation*), were deposited at a time roughly ranging from late Period 2 to early Period 3A at Harappa. Although few in number, these artifacts can provide a general idea of what the isotopic character of lead deposits in eastern Iran *may* be like, assuming, of course, they were obtained from that region.

Pieces of galena along with sheet-like lead fragments and a ring made of that metal (Figure 12.35 – MGK 1 to 12, & 14) were recovered in Period III and IV levels (ca. Harappa Period 2 to mid-Period 3) at the Helmand Civilization settlement of Mundigak (Casal 1961) in southern Afghanistan. These artifacts are now in the collections of the Centre de Recherches Archéologiques Indus-Balochistan, Asie Centrale et Orientale at the Musée Guimet, Paris, which is presently headed by Dr. Jean-François Jarrige. I was kindly allowed to extract lead from these artifacts, which were quite possible derived from the source just 10 km from Mundigak at Asad Qala, (Jarrige and Tosi 1981).

Also in the collections at Musée Guimet are a

number of lead artifacts from the ancient settlements of Mehrgarh and nearby Nausharo, which are located at the foot of one of the major passes connecting the Indus Valley to the central Balochistan highlands and beyond to the Helmand Basin. Dr. Jean-François Jarrige, who directed excavations at both sites, generously permitted lead to be extracted from these artifacts (not pictured) for analysis. The Mehrgarh artifacts are galena fragments from the site's Balochistan Tradition Neolithic levels (Period IIB – ca. 5000 BC). The artifact from Nausharo is a lead ring from the initial Indus Civilization levels (roughly equivalent to Period 3A at Harappa) at that site. The nearest lead sources are in the Khuzdar region, around 200 km to the southwest.

Two lead artifacts from the Indus Civilization city of Mohenjo-daro in northern Sindh were assayed. The first is a galena fragment (Figure 12.36 A) recovered during the surface surveys by the German-Italian mission to that site (Jansen and Urban 1984), which is now stored at the Department of Archaeology and Museums' Excavation Branch collection in Karachi. The other sample was extracted from a "surma" residue in small copper vessel (Figure 12.36 B) on display in the cases of the Mohenjo-daro site museum. Although the vessel is presumably from one of the early excavations at that site, no accession numbers or other identifying information could be found for it. The closest lead deposits to that site are those in the Khuzdar region – around 170 km to the west-northwest. It is recognized that, because the sample was taken from a copper vessel, the Pb isotope.

A flattened lead lump (Figure 12.37 – artifact BSR-5930) from the Indus site of Gola Dhoro (Bhan *et al.* 2004) in northern Saurashtra, Gujarat was sampled with the kind permission and assistance of two of that site's excavators, Dr. P. Ajithprasad and Dr. Ambika Patel of Department of Archaeology at Maharaja Sayajirao University, Gujarat. The artifact belongs to Phase-II, which is the "Classical/Urban" Harappan Period at the site.

The Pb isotope characteristics of silver artifacts from five sites were determined using ICP-MS. Most were sampled using the EDTA lead extraction technique. Immersion time in the sampling solution was tripled to six minutes because, presumably, only a trace amount of lead was present in the metal. Although lead was indeed extracted from silver items in amounts considerably lower than for those composed of lead, concentrations were still sufficient for isotopic analysis. Lead from one artifact (from Nagwada), which was in Madison undergoing other types of analysis, was brought into solution by dissolving precisely 0.02 grams of metal from it in ultra-pure nitric acid. Isotopic data for and descriptions of the silver artifacts discussed below can be found in Appendix 12.5. Site locations are noted on Figure 12.2.

A small silver ring (Figure 12.23 A – MGK 13) from Mundigak Period IV was sampled for Pb isotopes at the same time as the lead artifacts from that site (discussed above).

A detailed analysis of a silver ring fragment (Figure 12.38 A) from the site of Nagwada (Hegde *et al.* 1988) in the Rupen estuary of northern Gujarat was begun in collaboration with one of the excavators of that ancient settlement, Dr. Kuldeep Bhan of the Department of Archaeology at Maharaja Sayajirao University, Gujarat. The artifact is heavily corroded. BSE imaging (Figure 12.38 C) and EDS scans revealed that the silver (Ag) metal of the ring's exterior has undergone alteration to silver bromide (AgBr), encompassing some sand grains ($SiO_2$) from the sediment it was buried in as it did so. The interior of the artifact (Figure 12.38 D), however, is unaltered. Five WDS scans (Figure 12.38 B) were conducted across the center of this unaffected portion and then averaged in order to quantify the absolute amounts of silver, copper (Cu), lead and gold (Au) in the metal. The silver ring was found to be very pure ($\approx$ 98.5 %); even more so than those silver artifacts from Mohenjo-daro and Lothal that have been analyzed

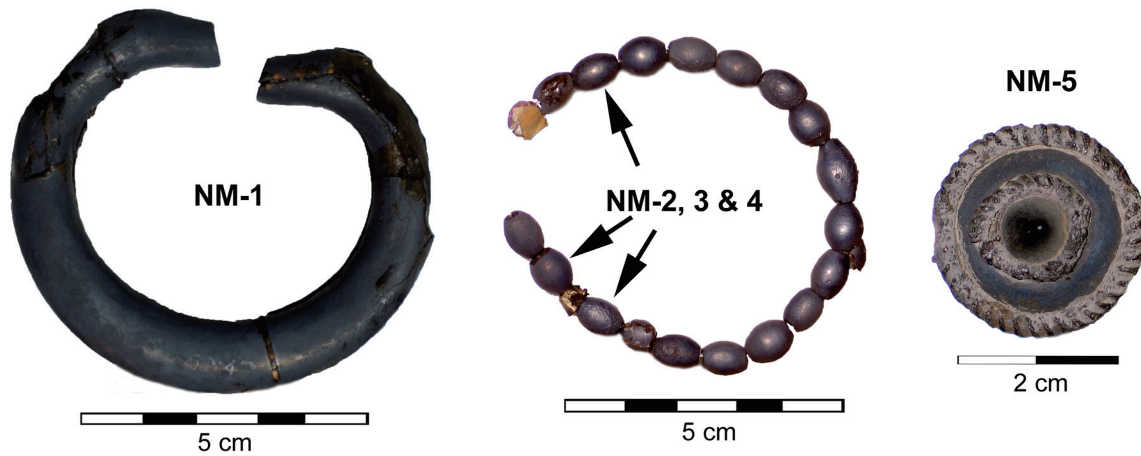



**Figure 12.39** Silver artifacts from Mohenjo-Daro sampled for this study.

(summarized in Kenoyer and Miller Table 5.3). Copper (≈ 1.5 %) makes up most of the ring's non-silver content. Although it is likely that copper was deliberately alloyed with the silver during production of the ring, it is not impossible that it was retained from the extraction of silver from copper or lead ores. Although very little lead was present in the metal (≈ 0.2 %), enough could be brought into solution (as described above) for isotopic analysis using the ICP-MS.

This tiny ring fragment is of special interest because it was from recovered from Nagwada's earliest occupational phase, which immediately precedes the Harappan Period at the site (Hegde *et al.* 1988: 62). Certain ceramics forms are found in this level and in equivalent contexts at several other sites in general vicinity (Dholavira, Sukotada, Moti Pipli – Figure 12.7), which exhibit close similarities to those used by the Early Harappan Amri-Nal and/or Kot Dijian peoples of southern Balochistan and Sindh (Possehl 1999: 603-609). These finds probably reflect the initial expansion of those cultures into the northern Gujarat area (Possehl 2002b: 40-41). If the silver used by Early Harappan peoples was extracted from lead ore as some have proposed (discussed in Chapter 4), then it will be of great interest to know whether or not the lead in the Nagwada ring is isotopically more analogous to the closest deposits of argentiferous lead in southern Rajasthan (specifically, the Zawar deposit and the Rampura-Agucha/Rajpura-Dariba belt – beginning around 225 km to the northeast of the site) or to the next nearest sources in the Khuzdar region (around 700 km away), which just so happens to be the northern part of the Amri-Nal culture area.

A small metal ring (Figure 12.37 – artifact BSR-7053) from Gola Dhoro was sampled at the same time as the flattened lead lump from the same site described above. It belongs to Phase-II, which is the "Classical/Urban" Harappan Period at the site. I have included it here with the silver artifacts because it was largely covered with a dark gray layer that is reminiscent of oxidized silver. However, the ring clearly has a high lead content (it may even be mostly lead). There are yellow patches on its surface that resemble lead oxidation and the EDTA solution in which it was washed was, unlike most silver artifacts that I have sampled, fully saturated with lead.

Lead was non-destructively extracted from five silver items excavated at Mohenjo-daro (Figure 12.39), which are currently on display at the National Museum in Karachi. The silver bangle sampled (NM-1) was one of two from a jewelry hoard (Marshall 1931b: Plate CXLVIII *in hoard*, Plate CLXIV b *restored*) found in a "Late Period" (roughly equivalent to Harappa Period 3C) room in the DK area (Mackay 1931a: 250, 1931c: 529). The other silver items sampled – three tiny beads (NM-2, 3 & 4) on a strand of 18 and a button or nose stud (NM-5), are from the same




**Figure 12.40** The Allahdino jewelry hoard - top image.
The 10 silver ornaments from the hoard sampled for this study - bottom image.

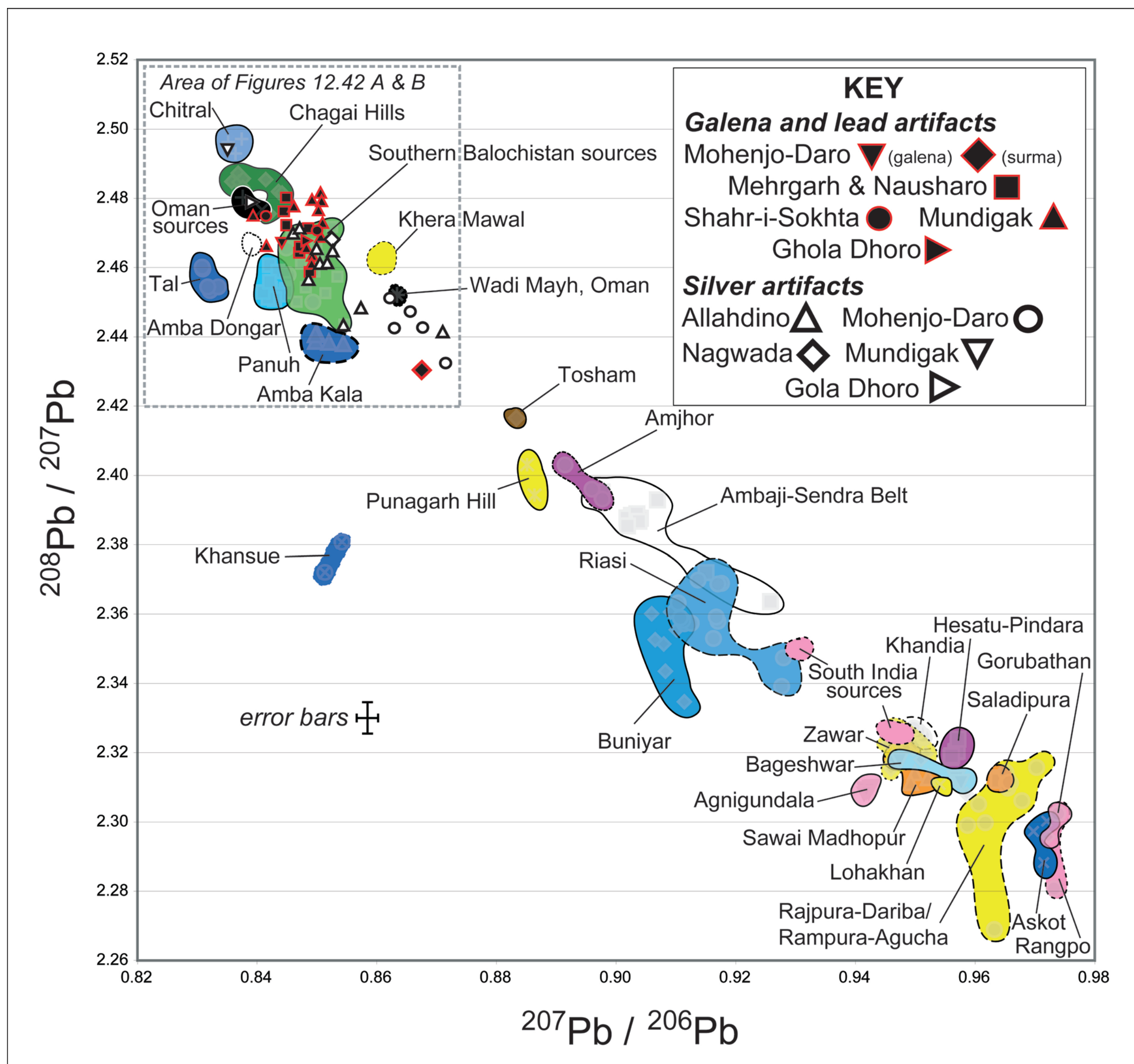



**Figure 12.41** Lead and silver artifacts from eight sites plotted against South Asian lead ore fields.

excavations but are not specifically identified in the site report.

Prof. Walter Fairservis discovered a jewelry hoard (Figure 12.40 *top image*) at the small Harappan site of Allahdino, in southern Sindh (1993: 109). Ten silver items from that hoard (Figure 12.40 *bottom image*) were sampled at the Department of Archaeology and Museum's head office in Karachi.

### *Results*

When the results of the Pb isotope analyses (appendices 12.4 and 12.5) of the lead and/or silver artifacts from the eight sites discussed above are placed on the bivariate plot of South Asian lead ore sources (Figure 12.41), all cluster in the upper left corner of the plot in two of the same general areas that many of the lead artifacts from Harappa previously fell. None appear to be even remotely related to sources in Jammu or Kashmir or to the many sources in Rajasthan and Gujarat (Amba Dongar excepted). Because all of the artifacts cluster in one section of the plot and a great many of them overlap, I have created two separate figures – one for lead (Figure 12.42 A) and one for silver artifacts (Figure 12.42 B), which focuses closely in on the area around where they fall. On these plots I have also placed the Pb data that was extrapolated (Appendix 12.6) from Stos-Gale's published (2001) isotope assays of galena samples

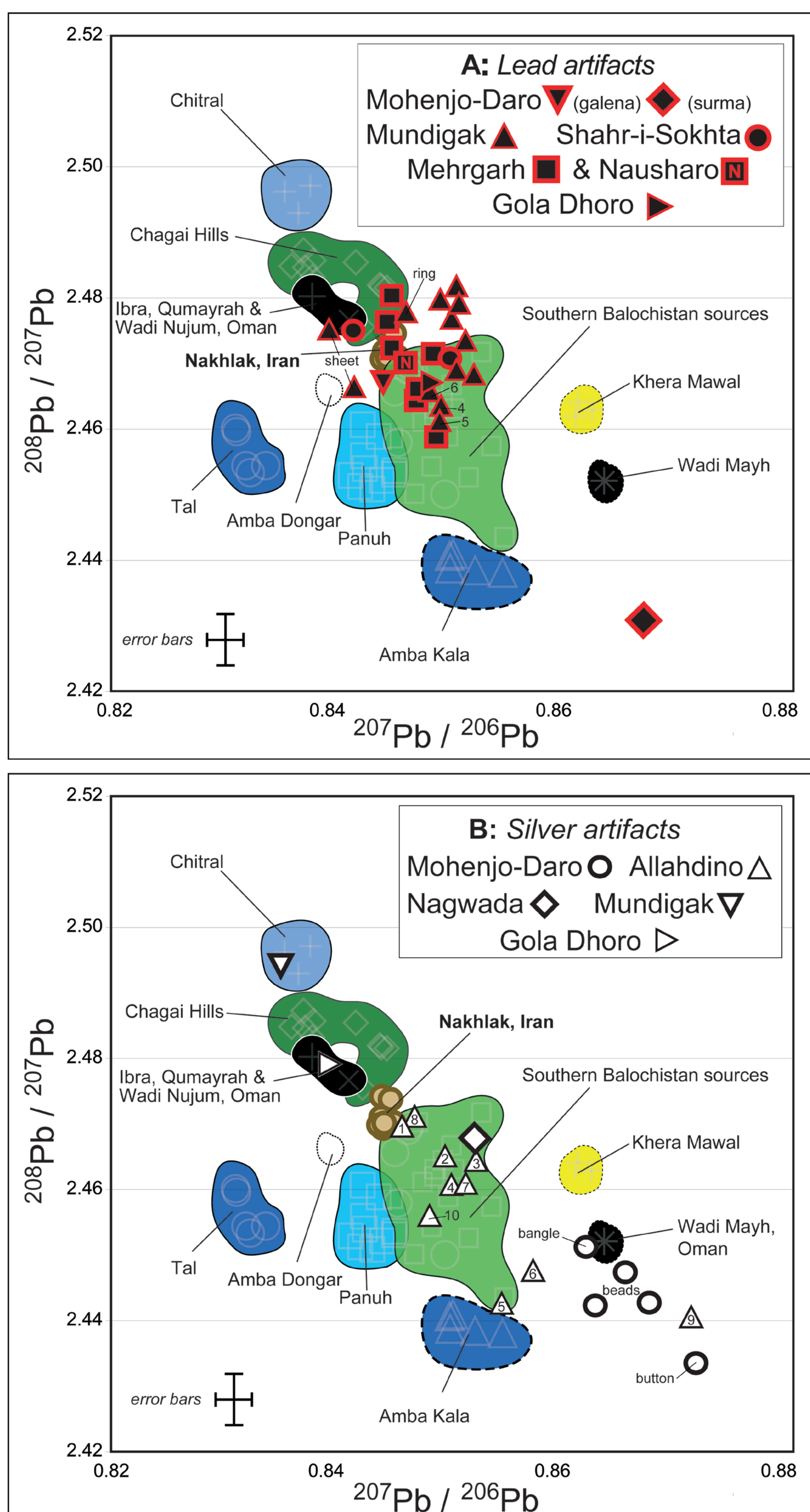



**Figure 12.42** [A] Lead artifacts from six sites plotted against select lead ore fields. [B] Silver artifacts from five sites plotted against select lead ore fields.

from the well-known argentiferous lead deposit at Nakhlak in central Iran.

*- Lead artifacts*

On Figure 12.42 A, twenty-six lead artifacts from six sites have been plotted in relation to select ore sources in South Asia, Oman and Iran. Before I begin to discuss the possible geologic provenience of those artifacts, first note that the *error bars*, when viewed from this closer perspective, are naturally much larger. Whereas on the previous bivariate plots the three areas where artifacts tended to fall/cluster were separated by distances that were far greater than the analytical uncertainty of the results, here many of the individual artifacts and groups of artifacts that I discuss are situated, relative to one another, within or near the range of possible error. Nevertheless, many artifacts cluster in distinct groups (rather than spread widely and randomly) that appear to be genuine and meaningful.

Starting with the Mohenjo-daro lead artifacts, we see that the single galena fragment from that site plots on the margins of the southern Balochistan source area. The cluster of Nakhlak (Iran) source samples is within the range of analytical error. However, given the location of the site, it is far more probable that the archaeological ore originally came from the former region. The lead extracted from the "surma" bottle falls in the "ambiguous" area where several ores, artifacts and slags from Harappa have previously plotted. Still, it would seem that the lead-based substance that was once in that bottle came from a different source area than that in the substances once held in similar bottles at Harappa or the galena fragment just discussed. It is, of course, possible that lead from multiple sources are present in the residue and what is we are seeing is an isotopic value plotting along a mixing line.

The Nausharo lead ring and most of the Mehrgarh galenas plot in an extended linear group, the majority of which fall within the area defined by the southern Balochistan sources. A few of the galena fragments, however, continue along the linear trend into areas where the Nakhlak and the Chagai Hills samples lie. It is difficult to judge whether or not the Mehrgarh galenas represent ores from a single source or multiple ones, although the linear manner in which they group indicates it may be the former. Perhaps when additional geologic samples from deposits in western Balochistan (Chagai region) are analyzed they will begin to isotopically overlap with the southern Balochistan deposits or vice versa. Although I doubt any of the archaeological ores actually came from the central Iran source (given that it is nearly 1400 km away and there were many other deposits that were closer), it is quite conceivable that Chagai Hills galena found its way to the Bolan Pass region.

The Mundigak lead artifacts plot in interesting ways. Of the ten galena fragments, seven (all of the unlabeled Mundigak data points on the figure) fall into a loose linear group (which may or may not represent a single source) that partly overlaps with the southern Balochistan deposits and then extends into an area where none of the geologic samples in the lead database lie. The three remaining Mundigak galenas (labeled by numbers 4 through 6) plot squarely within the southern Balochistan source area, with the Mehrgarh-Nausharo samples just discussed. Admittedly, given the degree of analytical uncertainty at this level, all of these lead ore artifacts could in reality be isotopically more similar (or dissimilar) than is evident here. However, I believe there are probably at least two sources represented among the Mundigak ores. Refer back to Figure 12.35 for a moment. The white weathered exteriors (probably cerussite) of artifacts MGK-04, 05 and 06 set them apart from other galenas, which have yellowish exteriors. These three ore fragments, which were excavated together, could actually be from a southern Balochistan source while the group of seven might be from the Asad Qala mine nearby Mundigak (samples from that deposit will eventually need to be

analyzed in order to confirm this). The lead ring and sheet fragments (noted on the figure) plot differently still. Isotopically, the ring falls on the margin of the area defined by the Chagai Hills source samples and lies adjacent to a few of the Mehrgarh galenas. The lead sheet fragments fall well away from the other Mundigak artifacts – one is adjacent to two Oman data points while the other plots nearby the single datapoint for the galena occurrence at Amba Dongar, Gujarat. The sheets have a white oxidized exterior like MGK-04 through 06 and could be a mixture lead from the same ore source and one or more others that are presently unknown. It is unlikely that they are actually from Oman or Gujarat, however.

Next we consider the two galena fragments from Shahr-i-Sokhta in eastern Iran. One of them plots in the area defined by the southern Balochistan source samples. However, it also groups closely with the cluster of Mundigak ores that *may* have been acquired from a deposit in the vicinity of that site. The second fragment falls in an area where data points for galena samples from both the Chagai region and Oman lie. It is entirely possible that the two ores could have actually have come from any of these areas. Close ties between Shahr-i-Sokhta and Mundigak clearly existed during the Integration Era of the Helmand Tradition (Shaffer 1992); the lead deposits in the Chagai region of western Balochistan are the closest (≈ 200 km) sources of that metal to the site; graves with Nal culture jars in the cemetery area at Shahr-i-Sokhta (Piperno 1979: 125) suggest connections with southern Balochistan; and there is good evidence that long-distance trade relationships extended as far as the Gulf region and Oman (Ratnagar 2004: 66-67). Unfortunately, the lead deposits in the most pertinent region, Iran, are either poorly characterized or (mostly) not characterized at all. Making a stronger statement about the provenience of these artifacts is, therefore, not possible at this time and, as I will discuss, it may not be possible using Pb isotope data alone and/or using an ICP-MS to make isotopic measurements.

Lastly, the flattened lead lump from Gola Dhoro appears to be composed of metal derived from southern Balochistan. It seems then that Harappans dwelling here had access to the same extensive raw material network through lead from that region was being acquired by Indus Civilization peoples all the way from Haryana in the north down to Gujarat in the south.

*- Silver artifacts*

Now we move on to the 19 silver objects from five sites. The data for these are plotted on Figure 12.42 B in relation to select lead sources in South Asia, Oman and Iran.

The ring from Mundigak plots with the three samples from the Shi Shi Valley lead occurrence in Chitral, NWFP. I believe it unlikely, however, that the silver for this item was extracted from that particular lead source as it somewhat "off the beaten path" and is not reported to be argentiferous (Tahirkheli *et al.* 1997). Certainly more accessible to residents of Mundigak would have been the silver-bearing lead deposits in the Ghorband and Panjshir valleys of north-central Afghanistan (Collins 1894; Pascoe 1931: 675). Those sources are located along the major trade and communication routes crossing the Hindu Kush of northern Afghanistan (Howland 1940) and, although unassayed, occur in the same general geologic terrain as the Chitral deposits. Of course, it is also possible that the ring contains lead from multiple sources and that its evident isotopic characteristics are a reflection of that rather and an individual deposit.

The data point for the Nagwada silver ring fragment falls within the area encompassed by the southern Balochistan lead deposits. Although it is possible that the isotopic characteristics of this artifact actually reflect the mixing of lead from multiple sources, it is very unlikely that one of those was the argentiferous deposit at Rajpura-Dariba in

southern Rajasthan, which is situated at the opposite end of the bivariate plot of the main ore sources (refer back to Figure 12.41). The only deposits anywhere in Rajasthan or Gujarat with isotopic characteristics that remotely resemble those of the lead in the ring is the small occurrence at Khera Mawal and the showing at Amba Dongar. However, even from the closer perspective used for the plot of silver items (Figure 12.42 B), the artifact and the data points for that source are separated by a distance greater than the range of possible analytical error. A geologic provenience of southern Balochistan for this silver ring from the initial occupation of Nagwada is very much consistent with other evidence for the movement of Early Harappan peoples from that region and Sindh into northern Gujarat during the early third millennium.

The five silver items sampled from Mohenjo-daro plot in a loose group around the somewhat ill-defined area where so many lead artifacts from Harappa have also fallen. The bangle is directly adjacent the single data point for the Wadi Mayh (Oman) lead occurrence. The three beads group nearby. The button/nose stud plots slightly farther away but still in a manner that seems to suggest that it and the others ornaments are very possibly composed of metal containing lead (either natural or added) from the same source or sources. The Wadi Mah occurrences is not, as far as I have been able to determine, known to be argentiferous and, therefore, the probable geologic source of the silver used to make these items remains "ambiguous."

Eight of the ten silver ornaments from the Allahdino hoard plot within the area defined by geologic samples from the southern Balochistan lead deposits. Of the two remaining pieces, one – AD-9 (number 9 on the figure), falls with the five Mohenjo-daro silver artifacts in the "ambiguous" area. The other – AD-6, could simply be an outlier of the southern Balochistan deposits (AD-5 lies nearby, within that defined area). On the other hand, AD-6 (and perhaps AD-5) might be on an isotopic mixing line between one of those deposits and the ambiguous "source" where AD-9 and the Mohenjo-daro items fall. Or it may be from silver extracted from a different source area, one that is not represented in the database. Whichever the case actually is, the isotopic characteristics of the lead in most of the Allahdino samples are analogous to the sources of that metal closest to the site itself. Still, it is important to note that two examples (AD-1 & AD-8) fall near (within the range of analytic uncertainty) the Nakhlak argentiferous lead deposit of central Iran and one (AD-5) lies similarly near to the Amba Kala deposit (also argentiferous) of Himachal Pradesh.

Lastly, the silver/lead ring from Gola Dhoro falls squarely among the cluster of three data points representing lead occurrences in Oman at Ibra, Qumayrah and Wadi Nujum. It also plots within the range of error for lead deposits in the Chagai Hills of far western Balochistan. However, if we assume for the time being that the ring is made from metal derived from only one deposit, then it seems more likely the source was probably in Oman rather than the Chagai Hills given the links between the Indus region and eastern Arabia during the Harappan Period.

### Interpretation of the Pb isotope data for lead and silver artifacts from all sites

Pb isotope assays have been made on 79 lead and/or silver artifacts from Harappa and eight other prehistoric sites in the Indus Valley and Helmand regions. When the results for all are placed on the bivariate plot of lead ore deposits (Figure 12.43) the data points representing them cluster in three main areas. Based on these patterns of clustering, the "probable geologic provenience" of each lead artifact from Harappa is stated in the final columns of appendices 12.2 and 12.3.

Those artifacts that cluster in the Pb isotope fields defined by the geologic samples from the

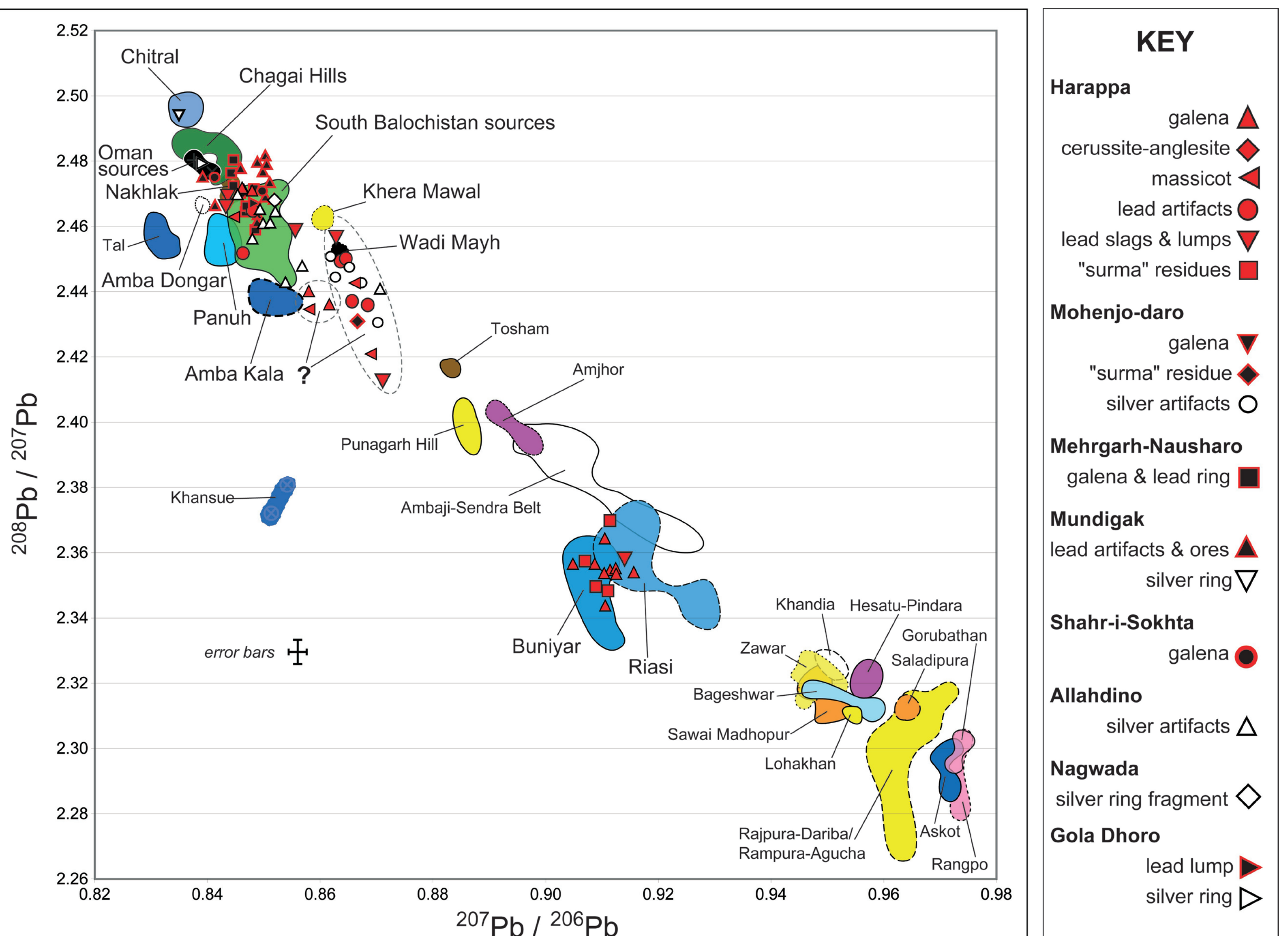



**Figure 12.43** Plot of all Pb isotope determinations for archaeological samples (lead & silver) from all sites against South Asian lead ore fields.

Jammu and Kashmir region (Buniyar and Riasi area deposits) are, at present, the most secure in terms of their geologic provenience associations. With the exception of a slight degree of overlap with the Ambaji-Sendra belt (which, in actuality, is due to just two data points that are distant outliers of the main group of Ambaji-Sendra belt assays), there are no lead sources in the database with isotopic characteristics that even remotely resemble this one. Of course, this may eventually change as more sources are analyzed. Until that time, however, I believe it can be stated with a high degree of confidence that the lead in these particular artifacts probably came from sources in "Jammu and Kashmir."

Conversely, the artifacts with the least secure geologic provenience associations are those that cluster in what I have repeatedly called the "ambiguous" area around the Wadi Mayh and Amba Kala deposits. Although many fall next (or are within the range of analytic error) to the data points for those three deposits, I am reluctant to make even a provisional provenience association for any of them because the "isotopic space" in this area so poorly defined in relation to known geologic sources. The characteristics that cause most of these artifacts to plot in this space *could* be due to the mixing of lead from two or more sources. Even if that is so, however, we may be certain that at least one geologic deposit with the same general isotopic characteristics as the artifacts in this cluster also exists and was exploited, simply because several of those artifacts are raw ores of lead (galena and massicot fragments from Harappa) that have not been subject to source mixing. In fact, there is probably more than one geologic deposit represented in this cluster and I have placed dashed ellipses on the figure around the areas where I think they could be. These ellipses are purely speculative and only further characterization of the geologic deposits around them (as well as of new ones) will allow us to determine if the artifacts that they group genuinely belong together. So although some of these lead and silver items may possibly come from sources in Oman or Himachal Pradesh, for the Harappa artifacts I can only state that their geologic proveniences are "unclear at this time"

Artifacts in the third cluster are the most difficult to interpret. They fall mainly in the southern Balochistan "field" defined by the Khuzdar and Kanrach Valley lead deposits. Some, however, extend beyond that field and plot on or near data points belonging to samples from deposits in Iran, Oman and the Chagai region, as well as into areas of the bivariate plot that are not currently defined by any geologic sources. Those that do this belong to either the Helmand Civilization sites of Mundigak and Shahr-i-Sokhta, where residents may have been exploiting some of the lead sources in the regions around their settlements, or to Mehrgarh, which may have been acquiring lead through long-distance trade networks extending to some of those very same source regions. It seems then almost certain that multiple geologic deposits dispersed across a wide geographic area are represented among the lead and silver artifacts making up this cluster.

The "fields" that are located in the section of the bivariate plot where artifacts in the third cluster fall are, at the present time, fairly distinct, i.e., there is minimal overlap between them. However, as additional ore samples from these and other sources are incorporated into the database there is reason to expect that they will begin to overlap with one another considerably more. That reason is because the geologic age (the principal factor influencing isotopic composition) of most of the metallogenic zones in which lead (and copper) is found in Balochistan, eastern Iran, southern Afghanistan and even Oman are *broadly* similar (Bazin and Hübner 1969; Samani 1998; Shams 1995b; Wolfart and Wittekindt 1980). One of the purposes for including data from the Nakhlak deposit of central Iran was to illustrate just how isotopically alike lead deposits from those different regions can be. An

artifact with measured Pb isotope values causing it to plot with the Nakhlak data points would be still be within the range of analytic error to sources in Oman, southern Balochistan and the Chagai Hills region (Figure 12.42 A shows this best). Admittedly, Pb isotope measurements made using an ICP-MS do leave something to be desired (namely, extremely high precision and useable $^{204}$Pb values) when attempting to assign artifacts to sources within the limited isotopic space that this cluster encompasses. TIMS-generated data would undoubtedly improve source resolution in this part of the bivariate plot by lowering analytic uncertainty and providing a third dimension for comparison. However, as the database of assayed deposits in the Indo-Iranian highlands and Oman increases, no amount of precision will enable one to differentiate overlapping areas that are isotopically identical. This could limit the ability to use Pb isotope data alone to identify the provenience metal artifacts from sites located within those regions.

The situation is entirely different for Harappa and sites in the Indus Valley because, as previously discussed, they are surrounded by regions in which the isotopic characteristics of the metallogenic zones within them are, on the whole, extremely different from one another. The precision provided by the ICP-MS is more than sufficient to differentiate artifacts coming from one regional zone or another. So as for the probable provenience of the artifacts from Harappa and other Indus sites that are among the third cluster under discussion, all fall into the field defined by the Khuzdar/Kanrach Valley data points. Although this field may eventually be obscured by data from other deposits, for now we can state, with a good degree of confidence, that the lead for those artifacts was acquired from nearest isotopically analogous sources – those in "southern Balochistan."

The same may be stated of the Nagwada ring and most of the silver artifacts from the Allahdino hoard. Although it is certainly possible the metal for those ornaments was extracted from isotopically analogous lead deposits in a different area (perhaps coming to the Indus region through trade with Mesopotamia as Ratnagar has suggested [2004: 199]), I believe that, with these new findings, the evidence that southern Balochistan was a silver source for Indus Civilization peoples is now fairly good. At least one of the Khuzdar occurrences (Gunga) is known to be highly argentiferous (Shams 1995b: 246) and sediment surveys of nalas (streams) coming off of the Mor Range in the lower Kanrach Valley area detected elevated levels of silver suggesting that the existence of sources in this region are quite good (Naseem 2002). Old lead mines and smelting areas are well-documented around Khuzdar area (Hassan 1989; Siddiqui and Sharp 1993) and the only silver artifacts reported in this region are from Sohr Damb/Nal (Hargreaves 1929), which is in vicinity of Gunga and these old workings. The Early Harappan Nal and Indus Civilization era Kulli occupations at that site and in the southern Balochistan highlands provide the cultural links through which silver could have made its way to Allahdino in lower Sindh and Nagwada in northern Gujarat. Short of discovering archaeological remains that document the cupellation of silver from lead deposits in this area, the evidence (isotopic, artifactual and circumstantial) that at least some Harappan silver likely came from southern Balochistan sources cannot get too much better.

## Ongoing studies of lead and silver artifacts and sources

Studies of lead and silver artifacts and their potential geologic sources continue. Analyses of such artifacts from the Indus cities of Dholavira and Rakhigarhi, as well as from the Bronze Age burial site of HD-10 (Salvatori 2001) in the Ra's al-Hadd region of Oman, were in progress as this book was being prepared for publication. These new Pb isotope assays are being conducted using either MC-ICP-MS or TIMS, which will provide useable $^{204}$Pb data and even more accurate $^{208}$Pb, $^{207}$Pb and $^{206}$Pb values.

Eventually, all of the artifacts and geologic samples ran on the old ICP-MS at the LARCH will be re-analyzed using these instruments. Although this work is ongoing, a few brief, preliminary observations can be made here.

Evidence continues to mount suggesting that southern Balochistan was a major source area for lead and silver during this period. Metal or raw ore derived from occurrences in that region, which was being used by Indus Civilization peoples at Harappa, Mohenjo-Daro, Allahdino, Nagwada and Gola Dhoro, was also being acquired by residents of both Rakhigarhi in Haryana and Dholavira in Gujarat. The deposits of southern Balochistan, specifically those in the Kanrach Valley, may have also been the source of four lead beads found in a cairn burial at HD-10 in Oman.

New source areas are also coming to light. Although residents of Dholavira acquired most of their lead from occurrences in southern Balochistan, a minor amount appears to have been derived from the Ambaji deposits of northeastern Gujarat.

## COPPER

The focus of this chapter now shifts to copper, which was undoubtedly a material of enormous importance not only for Indus Civilization peoples but also for their contemporaries in many parts of Asia and Europe. Only through a concerted research program that combines isotopic and compositional analyses with stylistic and contextual studies (*a la* the recent work by Lloyd Weeks [2004] on copper alloy artifacts from Bronze Age sites in the United Arab Emirates) will it be possible to begin to fully understand the exploitation, production, trade, use and re-use of this metal at Harappa and elsewhere in ancient South Asia. My intention here is not that ambitious. In this section, I use Pb isotope analysis to compare the few examples of raw copper ore that have been recovered at Harappa to a small database of isotopic assays made of geologic samples and copper production debris (slags) representing sources in five broad regions from which Indus Civilization peoples may have acquired this important metal. Although this study is small in size, it is the first direct analytic comparison of copper artifacts from Harappa to geologic materials from potential sources since Sana Ullah's early work (1940).

### Copper ore at Harappa

Only seven copper minerals have been identified from among the more than 2600 copper or copper-alloy artifacts recovered at Harappa. In addition, the only vitrified craft indicators related to this metal are things like crucible and kiln-wall fragments that are made of clay-based materials (Miller 1999: 414). The scarcity of ores and the absence of siliceous slags is indicative of production activities that involved melting and working metal that had already been processed in some way rather than the smelting of raw copper ore in order to extract metal (Miller 1994b: 505). This is not at all surprising. It certainly would have made little sense to transport large amounts of raw ore over 400 km to the site (the minimum distance to deposits of any significance) when it could have been reduced to easily manageable quantities of metal at or closer to its source. The seven ores (Appendix 12.9) – four small fragments of chalcocite and three of malachite (Figure 12.44); all come from the south slope of Mound E, which is where the heaviest concentration of copper production debris was found (Miller 1999: 414-415). All are from surface or disturbed contexts except for a single malachite fragment from Period 3C levels.

### The Pb isotope database for copper ore sources

Kenoyer and Miller suggested (1999: 115) that Harappan metalsmiths might have acquired copper from deposits in four main source regions: the broad region west of the Indus Valley that includes the

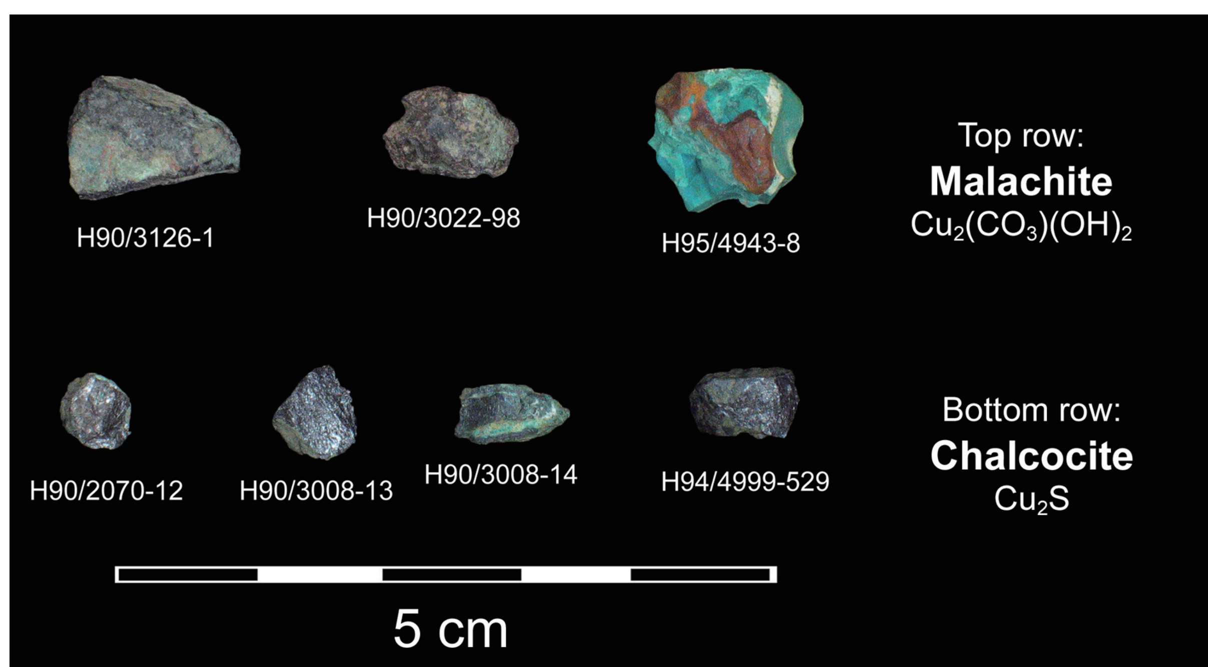



**Figure 12.44** Seven raw copper ore artifacts from Harappa.

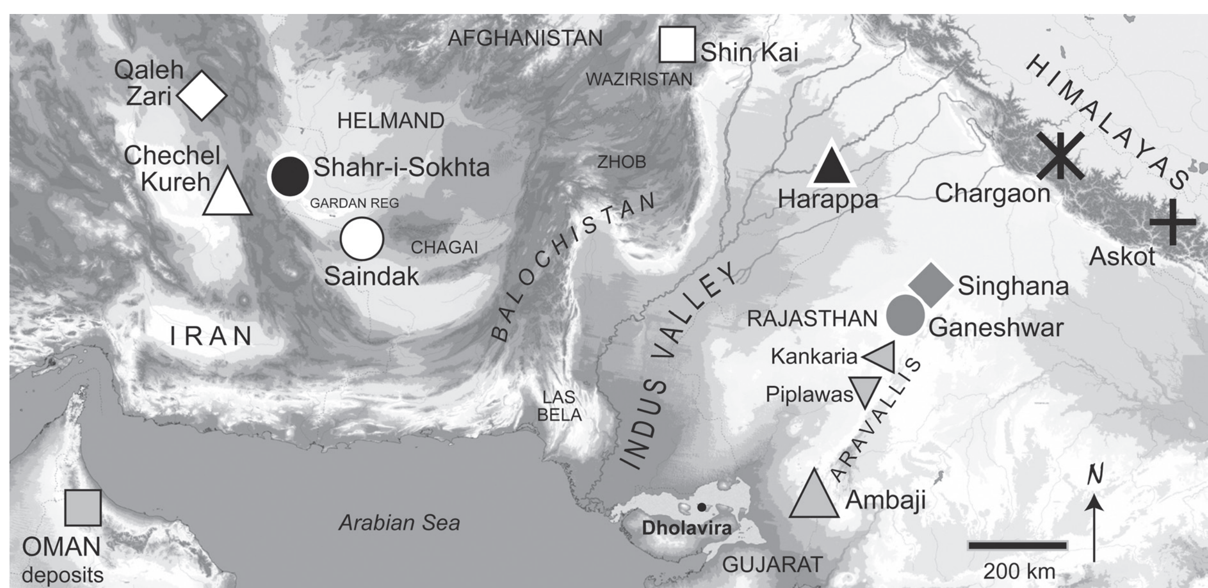



**Figure 12.45** Assayed copper ore deposits and archaeological sites featured in this section.

combined areas of Balochistan and Afghanistan; Oman; the Aravalli mountain range of Rajasthan and northern Gujarat; and, perhaps, Iran. I basically agree with this but would add a fifth region – the Himalayas and related highland areas of northern India and Pakistan, as a potential source area, especially since it now appears that some of the lead found at Harappa was acquired from deposits in Jammu and Kashmir.

Prior to this study, Pb isotope assays of copper ores had only been made for deposits located in Oman, Iran and the Aravallis. The database (Appendix 12.8) presented here includes isotope values extrapolated from those previously published data along with new analyses of copper ores and/or slags from seven locations in Balochistan, Waziristan, the Himalayas and the Aravallis. Below, I focus mainly on the assayed the deposits that are featured in the database (Figure 12.45). For more comprehensive

overviews that detail individual occurrences and the many old workings found in these regions see the following: for Pakistan and India (Ahmad 1969; Chakrabarti and Lahiri 1996; Geological Survey of India 1994; Kazmi and Jan 1997; Nandan *et al*. 1991); Afghanistan (ESCAP 1995: Peters *et al*. 2007); Iran (Bazin and Hübner 1969); and for Oman (Weeks 2004).

### *The Aravallis*

The Aravalli Range of Rajasthan and northern Gujarat is considered by many to have likely been one









**Figure 12.46** Top image - Looking toward the Khetri mines from Singhana with the small "mountains" of slag in the foreground. Bottom images - Fifteen meter high layered slag heap at Singhana.

of the main sources (some believe *the* main source) for the copper used by Indus Civilization peoples (Agrawal 2000; Agrawala 1984; Allchin and Allchin 1982; Asthana 1993; Chakrabarti and Lahiri 1996; Dhavalikar 1997; Kenoyer and Miller 1999; Pascoe 1931; Sana Ullah 1940). Nineteen major zones of base metal mineralization occur intermittently along its approximately 600 km length and old workings have been noted in every one of them (Geological Survey of India 1994). The richest deposits are found in the northern part of the range in the zone known as the Khetri "Copper Belt." Although it was not possible to obtain ore samples from deposits within this zone, copper smelting slags from two locations were provided by Kishore Raghubans, then a PhD student at M.S. University, Baroda who did his dissertation research on the Ganeshwar-Jodhpura culture complex, which was an indigenous, non-urbanized Chalcolithic society inhabiting the northern Aravalli region during the third millennium BC (Agrawala and Kumar 1982). The first set of slags was acquired at Singhana (near Khetri), where the numerous small hills (heaps) composed entirely of smelting debris provide an indication of the intensity and duration of the copper extraction/production activities that have taken place in this region (Figure 12.46). The second set comes from a smelting area located less than one kilometer from the site of Ganeshwar, where more than 5000 of copper artifacts were recovered from third millennium BC levels (Hooja and Kumar 1997: 328). From here and from other Ganeshwar-Jodhpura culture settlements along the Khetri copper belt, Harappan consumers would have been living only from 100 to 150 km away in the southern Haryana.

In 1985, Hegde and Ericson conducted Pb isotope assays of single chalcopyrite samples from five deposits in the Aravallis. The values produced for two of those samples (from Khetri and Kho Dariba) were not even remotely comparable to other Pb isotope determinations made for massive sulfide deposits in the Aravallis or, for that matter, to any typical Pb-Pb isochron (Dickin 2004: 149-151). Until the accuracy of those particular cases can be confirmed they will not be used. Hegde and Ericson's published values from the other three samples do, however, appear to be accurate. The datapoint for a chalcopyrite sample from the Ambaji deposit (discussed below) is consistent with both the previously published TIMS data (Deb *et al*. 1989) and the analyses that I have made on samples from that occurrence. Details on the two remaining assayed deposits (Kankaria and Piplawas) are scarce but they are reported to be located in the central portion of the Aravalli Range.

The Ambaji polymetallic (Pb-Zn-Cu) sulfide deposit is located in the southernmost portion of the Aravalli Range. Old pits and slag fields extending for several kilometers can be found in this area (recall Figure 12.15), which lay only 150 km to the northeast of the Harappan site of Nagwada. Literary evidence and $^{14}C$ dates from beams in deep (480 m) disused mine shafts suggest that ore has been extracted here since at least the first century BC (Nandan *et al*. 1981: 58). Previous isotopic characterizations of this deposit were made using galena samples (Deb *et al*. 1989). Although the isotope values were expected more or less identical, new assays of ten chalcopyrite samples collected from the Gujarat Mineral Development Corporation's open pit mine at Ambaji were made for this database.

***The Himalayas***

Geologists conducting fieldwork in areas of the Himalayas ranging from Kashmir to Uttaranchal have noted hundreds of old mine shafts, open pits and/or slag heaps related to the extraction and production of copper (Dass *et al*. 1964; Middlemiss 1929; Nandan *et al*. 1981; Sharma 2002). Dr. D.P. Agrawal correctly observed (1999) that this broad region has largely been overlooked in past studies of ancient metallurgy and he singled out the extensive polymetallic sulphide deposit at Askot in eastern Uttaranchal (previously discussed in the relation to the lead ore database) as an

important potential source for ancient consumers of copper in the northern part of the Subcontinent. The seven assays from this location in the copper database were made on samples provided by Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology, Dehra Dun.

Chalcopyrite (reported as pyrite – Director - Punjab Haryana and Himachal Pradesh Circle - Geological Survey of India 1971: 188) occurring in a granite pegmatite was collected near Chargaon (Figure 12.47) in the Kinnaur District, Himachal Pradesh (N 31° 30' 55", E 78° 07' 10"). Although this mineral appeared to be a minor accessory ore in what is reported as an old lead-silver mine (neither of those metals were located, however), five assays were included in the database because they are the only other copper minerals from a Himalayan deposit, besides those from Askot, that I currently had in my possession. There are many other potential copper sources across this region remaining to be characterized.

***Sources west of the Indus Valley***

Porphyry copper deposits of *broadly* similar geologic ages are found across the western Balochistan – eastern Afghanistan regions (Afghanistan Geological Survey 2006; Chmyriov *et al*. 1973; ESCAP 1995; Ludington *et al*. 2007; Sillitoe 1978). One of the largest occurs in Cretaceous to Oligocene era island arc volcanic rocks in Balochistan's Chagai district (Ahmad 1975: 40-46; Shams 1995b). The extensive slag fields found in that region (Vredenburg 1901: 292) and directly to the north in the Gardan Reg area of southwestern Afghanistan (Dales 1971; Dales and Flam 1969) bear testament to the intensive exploitation of these deposits during the early to mid-third millennium BC (Kenoyer and Miller 1999). Seven ore samples from the Saindak occurrence (Wolfe 1974) were provided by Abdul Razique and Razzaq Abdul-Manan of Tethyan Copper Ltd.

Copper occurrences are also found in the ophiolite sequences that were emplaced during the Cretaceous to Lower Eocene eras along the western





**Figure 12.47** View of mine and detail of copper oxidation at Chargaon, Kinnaur District, Himachal Pradesh.



**Figure 12.48** Shin Kai copper prospect North Waziristan and detail of the copper oxidation/mineralization found there.

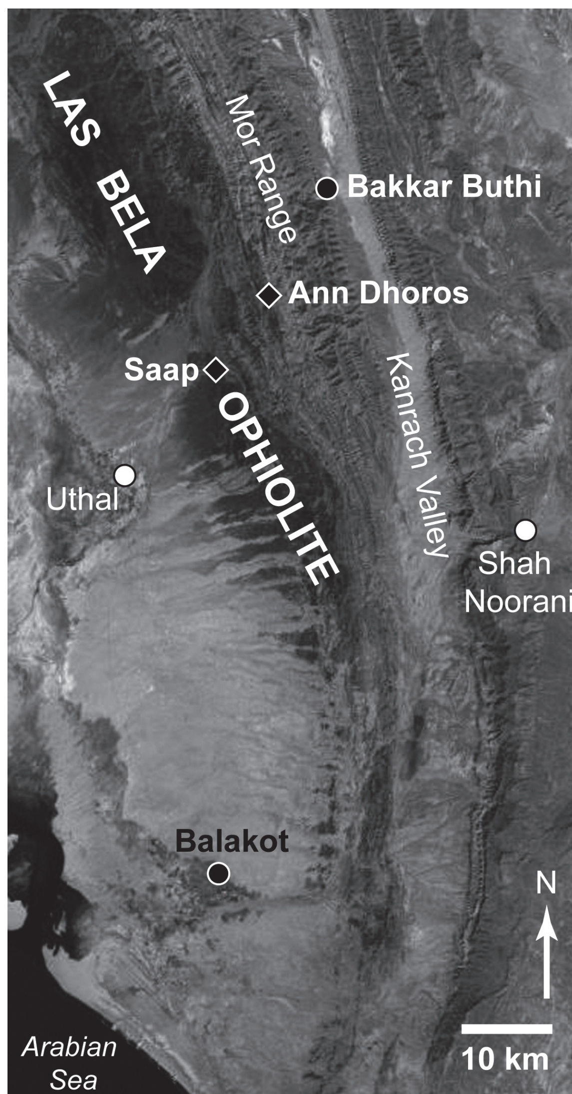



**Figure 12.49** Copper deposits and towns (Harappan and modern) in relation to the Las Bela ophiolite of southern Balochistan.

margins (the "Indus suture zone") of the Indus Basin at various points from the NWFP to Balochistan (Asrarullah *et al.* 1979). Several prospects are located within the Waziristan ophiolite (Badshah 1985), around 60 km up the Tochi River from where Neolithic and Early Harappan settlements of the Bannu Basin lie (Khan *et al.* 1988). In June of 2001, chalcopyrite and malachite was collected for this study from the Shin Kai prospect (Figure 12.48) near Mohammad Khel (Badshah *et al.* 1997) (≈ N 32° 55', E 69° 52'). Several minor deposits of the same nature are also found in the Zhob ophiolite (Heron and Crookshank 1954: 58-59) some 150 km to the south-southwest.

One potential source of copper from which samples have not yet been acquired for this study but is still very much worth mentioning here is the Las Bela ophiolite of southern Balochistan. "Massive copper sulphide prospects" are found between 15 to 30 km northeast of Uthal town at Saap and Ann Dhoros (Ahsan and Quraishi 1997: 44-45). Although these are said to have "no economic value" (ibid.) by today's standards, they are quite likely the very same places "in the hills between Liari and Bela" where 19th and early 20th reports indicated copper could be found in "large quantities" (Gazetteer of Las Bela 1907: 118). Del'Hoste (1844) related a colorful account by two

Hindu traders who said that they had easily smelted a good quantity of the metal from this source before they were run out of the area under threats from the local tribal chief of being "burned alive" if they returned.

Although they are trifling in relation to copper deposits in most of the other source areas discussed in this section, the Las Bela ophiolite occurrences are important because there were permanent Harappan settlements located in the vicinity (Figure 12.49). Bakkar Buthi lies just 20 km to northeast across the Mor Range and Balakot is situated around 50 km due south. All of the other potential sources are in regions external to the "core area" of Indus Civilization sites. Although it is unfortunate that I am not able to include samples from these deposits in the copper database, it still may be possible to examine them by proxy. Although the lead deposits in the Kanrach Valley are hosted in Jurassic sedimentary rocks, the mineralization is thought to be associated with the Las Bela ophiolite zone (Zaigham and Mallick 2000: 487). The isotopic character of the copper deposits *might*, therefore, be similar to those of the Kanrach Valley galena samples.

***Iran***

The copper deposits of Iran are numerous, widespread and have evidently been exploited since antiquity (Bazin and Hübner 1969: 4-6; Berthoud *et al*. 1976; Wertime 1968). For Indus Civilization consumers, however, they would have been rather remote – the nearest are more than 1,100 km west of Harappa as the crow flies. Hauptmann and others recently (2003) conducted a Pb isotope analysis on samples from two copper deposits in eastern Iran (Chechel Kureh and Qaleh Zari) and set of copper ores, slags and artifacts from Shahr-i-Sokhta. The isotopic values for the archaeological ores (which have been included in this database along with those for the two geologic deposits) most closely matched those of the samples from the Qaleh Zari source, 300 km northwest of the site.

***Oman***

The exploitation and production of copper by the ancient peoples of the eastern Arabian Peninsula region (Figure 12.50) has been the subject of much study (Berthoud and Cleuziou 1983; Craddock *et al.* 2003; Prange 1999; Weeks 2004; Weisgerber 1984). Some feel that metal from deposits in Oman made its way to Harappan consumers (Kenoyer and Miller 1999) while others are doubtful that the region was an important source (Agrawala 2000; Chakrabarti 1998). The existence of trade links between the Indus Valley

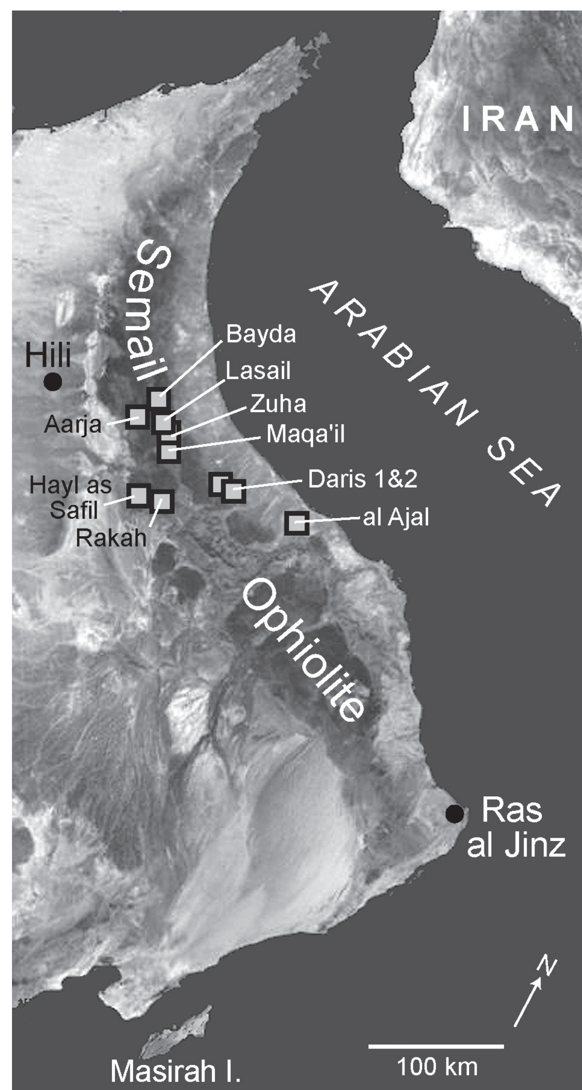



**Figure 12.50** Isotopically assayed massive sulphide deposits and sites having Harappan materials in Oman.

and this region are not in doubt, however. Harappan artifacts have been found at coastal settlements like Ras al Jinz (Cleuziou and Tosi 1994) and at inland oasis sites like Hili (Cleuziou and Vogt 1985).

Most copper in Oman occurs in massive sulphides deposits within ophiolites that are located either on the mainland of the eastern Arabian Peninsula (the Semail ophiolite) or on Masirah Island, just off of the country's southeastern coast (Weeks 2004: 12-14). Non-ophiolitic deposits exist but are minor in nature (ibid.). Pb isotope analyses of massive sulphide ores (usually chalcopyrite or pyrite) from eleven deposits in this region have been conducted by Chen and Pallister (1981) and Calvez and Lescuyer (1991). The assayed deposits include one non-ophiolitic source (al Ajal) and ten occurrences within the Semail ophiolite (location names are in the second column of Appendix 12.8 and on Figure 12.50).

### Analysis and results

In addition to the seven copper ore fragments from Harappa, Pb isotope assays were made for 49 ores and/or slags from deposits in each of the potential source areas discussed above. Ore samples (archaeological and geologic) were brought into solution by dissolving 0.02 grams of fresh material from them in ultra-pure nitric acid. Slag samples (15 each from Singhana and the smelting area near Ganeshwar) were crushed into a coarse powder and then examined under low magnification for any minute copper prills that could be used for analysis. When no metal could be found or the sample weight could not be reached, the siliceous part of the slag was used. Many examples had patches with a distinct greenish cast, which were preferred for analysis because the coloring was presumably due to copper content. Although the sample weight for some the slags was doubled to 0.04 grams in an effort to get more lead into solution, in exactly half of those analyzed there was still too little of it for the ICP-MS to make accurate measurements. In the end, Pb isotope data was obtained for 11 of the 15 Ganeshwar slags but only for four of the slags from Singhana.

The ores and slags analyzed at the LARCH, together with the previously published Pb isotope values, provide 85 datapoints representing copper deposits in the five potential source areas being considered here. When their ratios are placed on a bivariate plot ($^{208}Pb/^{207}Pb$ to $^{207}Pb/^{206}Pb$) along with those of the seven archaeological copper ores from Harappa, they spread widely, clustering in three areas (Figure 12.51 A). The chalcopyrite samples from Chargaon mine in Himachal Pradesh cluster in the upper left portion of the plot while those from the polymetallic sulphide deposit at Askot, Uttaranchal fall at the other extreme in the bottom right corner. Plotting along with the latter group are the datapoints for the assays that Hegde and Ericson (1985) conducted on samples from the Kankaria and Piplawas copper deposits of central Rajasthan. All of the remaining source samples, along with the ores from Harappa, fall in a cluster of largely overlapping groups in the center of the plot. The isotopic characteristics of the artifacts are clearly much different from either of the two Himalayan sources or the samples from central Rajasthan. This does not mean, however, that the Harappan ore fragments could not have come from other copper occurrences in those regions – just not these particular deposits or, most probably, not from any other deposits that are geologically related to them.

For Figure 12.51 B, the area of the main cluster in which the Harappan artifacts fall has been enlarged. Starting from the bottom left of the plot; the datapoints for the Ambaji mine in northern Gujarat cluster in a fairly well-defined group and are consistent with the single assay that Hegde and Ericson (1985) conducted for that deposit (noted on the plot with "H&E"). Although two Singhana slag samples representing the Khetri copper belt of northern Rajasthan fall nearby, most from that zone (including the Ganeshwar slags) cluster higher to the

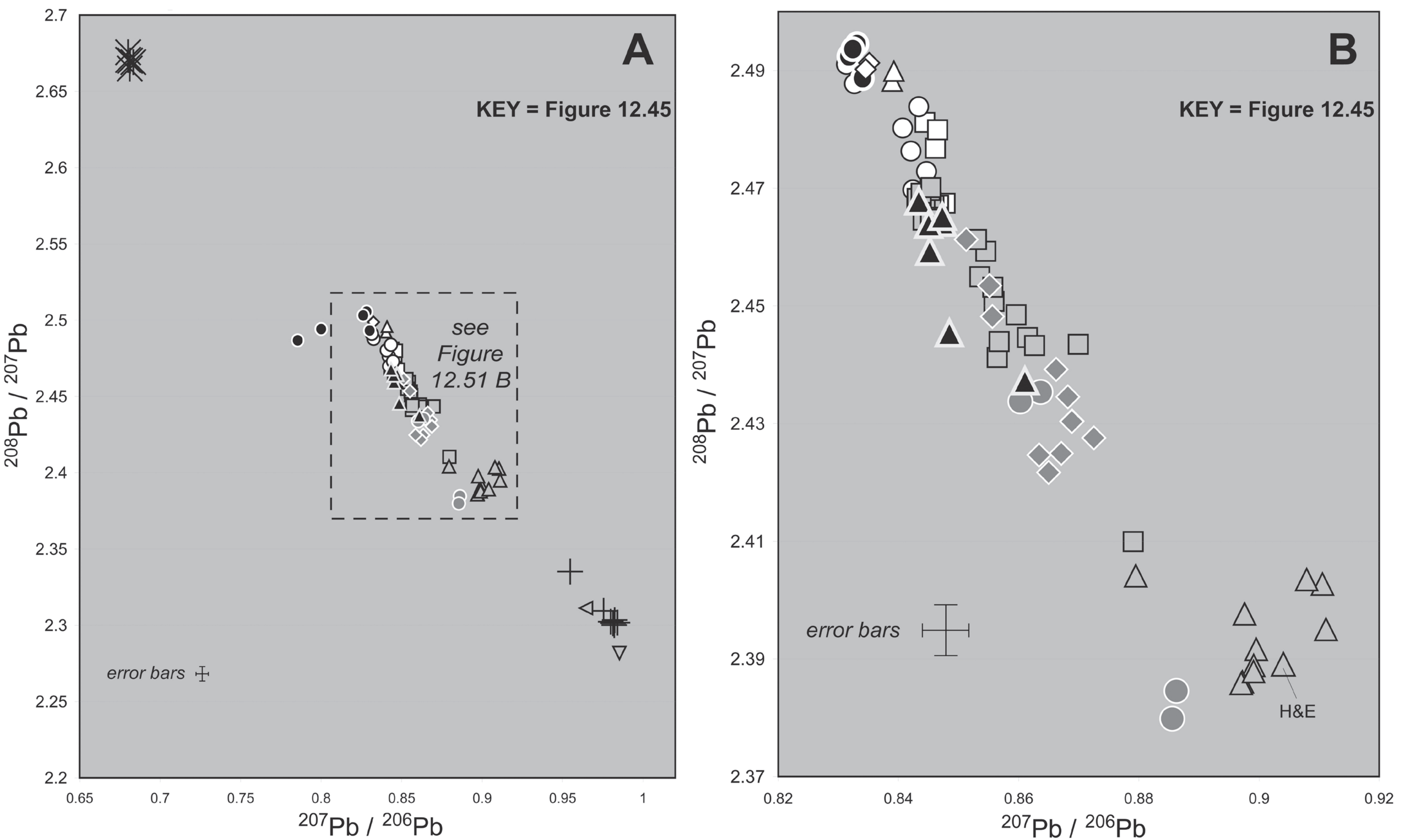



**Figure 12.51** **[A]** Pb isotope ratios for seven copper ore fragments from Harappa plotted against the ratios for samples (ores & slags) from seven copper sources in South Asia and Oman. **[B]** Pb isotope ratios for seven copper ore fragments from Harappa plotted against the ratios for samples (ores & slags) from select copper sources in South Asia and Oman.

left, in the middle of the plot. From that point begins the area where most of the datapoints for the various Oman sulphide assays fall. Three of the Ganeshwar slags plot there as well. The Oman assays terminate in a tight group (it is difficult to see on the plot but there are nine data points there) exactly at the point where the linear clusters of the Shin Kai (Waziristan) and Saindak (Chagai) datapoints begin, overlapping with several of them. The latter two groups extend from there to the point where the Iranian ore samples (geologic and archaeological) begin, with two of the Saindak datapoints overlapping with the Shahr-i-Sokhta artifacts and Qaleh Zari deposit samples.

The datapoints for five of the seven copper ores from Harappa fall upon (or directly adjacent to) the small area where the Oman, Chagai and Waziristan samples overlap that. This is most definitely a situation where having high precision isotope ratios and useable $^{204}$Pb values might be of great benefit in helping to differentiate sources and resolve the provenience of artifacts. Or it might not. The Waziristan and Semail ophiolites both formed in the mid-to-late Cretaceous era (Gnos *et al.* 1998; Weeks 2004: 9) as did some of the older intrusive volcanic rocks that host the Saindak deposit (Shams 1995b: 243-244). Therefore, these massive sulphide occurrences (and others, like the occurrences in the Zhob and Las Bela ophiolites, of roughly equivalent age) and porphyry copper deposits may ultimately be indistinguishable from one another using Pb isotope data alone. Of the remaining two Harappan ores; one plots with two of the Singhana slags (but within the range of error to the Oman cluster) and another falls parallel to but apart from where some of the Oman samples and Ganeshwar slags group. The former could be from the Khetri copper belt but I would feel more confident in such an assessment if 1) the samples representing that source were ores rather than slags and 2) the analytical precision were better than it is.

It is possible to state that the Harappan ores probably do not come from those deposits in the database representing eastern Iran, southern Rajasthan or the Himalayas. Five of them could be from sources in Oman or from geologically similar deposits located in regions to the west of the Indus Valley like Waziristan or western Balochistan. Of the remaining two, the provenience of one is unclear (perhaps it comes from Western sources also) while the other *may* have come from the Khetri copper belt of northern Rajasthan.

#### A brief note on further and ongoing studies of Harappan copper

Recently, twelve copper alloy artifacts from Harappa were assayed using TIMS and compared to the copper database presented in this section (Hoffman and Miller 2009). The results largely mirrored those for the seven copper ore fragments from Harappa. That is to say, the Pb isotope characteristics of the artifacts suggested that all or most were made from metal derived from sources to the west of the Indus region or Oman rather than those in the Rajasthan.

Pb isotope studies of copper ores and alloy objects from the Indus city of Dholavira are just beginning. However, the initial data indicate that both metal and raw ore from the Ambaji deposits of northern Gujarat were being acquired by site residents. Some copper from a source either west of the Indus region or in Oman also seems to have been used at the city. However, if the trend of the preliminary results continues then the primary source of copper for residents of Dholavira may well have been to the east at Ambaji.

## COMPARISON OF THE LEAD AND COPPER DATASETS

Many of the metal ore sources featured in this chapter are dominated by either lead mineralization or copper mineralization – e.g., the Kanrach Valley

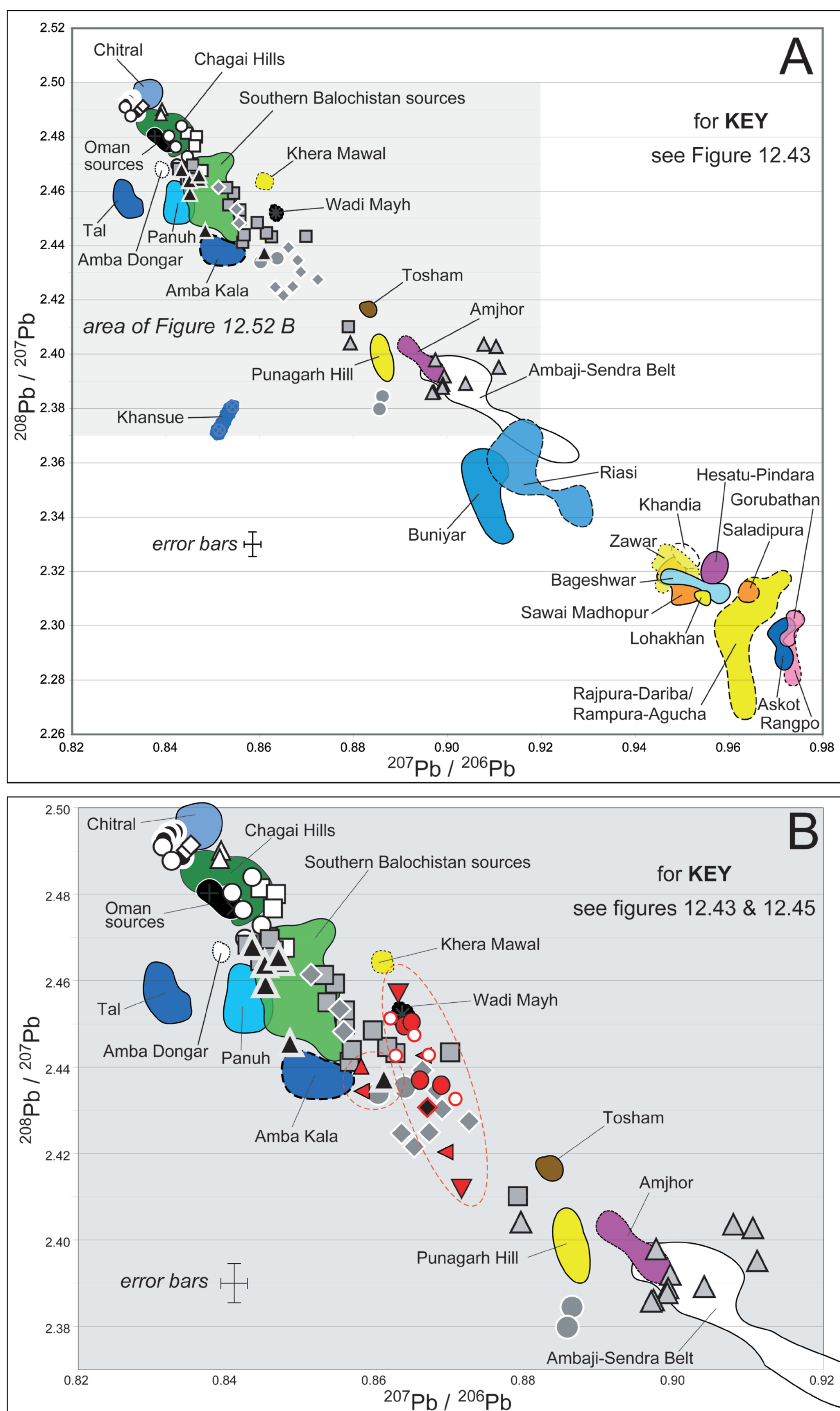



**Figure 12.52** **[A]** Pb isotope data for copper ores and artifacts superimposed on the "fields" of the main body of lead deposits. **[B]** Select copper ore data & lead "fields" plotted with copper and select lead artifacts.

(lead) and Khetri (copper) deposits. Other sources, like Ambaji and Askot, are rich in both metals. Rather than trying to evaluate all metal artifacts in relation to sources with very different and complex geologies, a decision was made early on in this study to treat lead and copper separately, the idea being, as it were, to compare apples-to-apples and oranges-to-oranges. So, two databases were assembled that contained Pb isotope assays made one just one or the other type of material rather than including all analyses made for a metallogenic zone or deposit. For instance, Calvez and Lescuyer (1991) produced Pb isotope data for galenas, copper-bearing massive sulphides, gossans, pelagic sediments and volcanic rocks from locations in northern Oman. The galena assay values from that study went into the lead ore database and the sulphides into the copper database – the rest were excluded. However, now that the main comparative studies are complete, it may prove informative to briefly evaluate the databases in relation to one another and to compare certain artifacts to both of the databases combined.

In Figure 12.52 A, I have superimposed the Pb isotope data for the main cluster copper sources and artifacts (Figure 12.51 B) directly on the bivariate plot of the main body of lead ore fields. All of the copper data falls in the upper left quarter of the plot. This area is enlarged for Figure 12.52 B, where I have also added the data points and dashed ellipses for those lead artifacts that clustered in the "ambiguous" area of the lead deposits database.

The first thing that is evident from these plots is the way in which the Pb isotope assays of copper and lead samples from the same metallogenic zones, not at all unexpectedly, tend to correlate well with one another. The copper samples from the Saindak deposit (white circles with black borders) in the western Chagai District of Balochistan plot either on or directly adjacent to the isotope field (dark green) defined by galena fragments from related porphyritic deposits (Rekodiq and Koh-i-Sultan) located nearby. Copper and lead samples from the Ambaji mine similarly correlate with one another. In future versions of these databases, assays of both copper and lead minerals from these sources and others like them can probably be safely used together. It remains to be determined whether or not the same will be true for lead and copper deposits found within a common metalliferous zone or just located in the same regions. However, because the two databases are far from being complete, it is worth the effort to briefly consider where certain lead and copper artifacts plot in relation to geologic samples in the opposite databases (i.e. lead-to-copper and copper-to-lead). This might, at least provisionally, help to fill some of the existing isotopic "gaps" or "ambiguous areas."

Note that on Figure 12.52 B the five copper ores from Harappa that cluster closest together, all plot within the isotope field for the southern Balochistan lead deposits (and a sixth falls adjacent to it). Most of the galena samples defining that field are from occurrences in the Kanrach Valley, which (as discussed above) may be geologically (and isotopically) related to the nearby Las Bela ophiolite and the copper-bearing sulphide deposits within it. Even if those copper and lead deposits are shown to be isotopically analogous it would not rule out the other possible sources (Oman, Waziristan, Chagai) for the archaeological ores. It would, however, establish the southern Balochistan region as an isotopically analogous source area in which both copper deposits and Indus Civilization settlements can be found.

Consider also the various lead artifacts from Harappa and silver artifacts from Mohenjo-daro (noted on Figure 12.52 B as white circles with red borders) that cluster in the "ambiguous" area on the bivariate plot of lead sources. Many of the slags representing the Khetri copper belt also plot in that area. Although this is an interesting association, it must be examined realistically. Lead mineralization is exceedingly rare in this part of northern Rajasthan. One of the few occurrences that have been reported

– trace galena in a deep coring at Saladipura (Deb *et al*. 1989), is isotopically very unlike the slags and the artifacts. Silver is extracted today from argentiferous copper ores in the Khetri belt (Rao *et al*. 1997). However, there is no evidence that it was exploited there during earlier eras, nor have any silver artifacts reported been reported from Ganeshwar-Jodhpura sites in the region. Still, although the chance that the metal for these lead and silver artifacts actually came from northern Rajasthan is very slim, it is important to keep an open mind to the possibility.

A final point to note is how, collectively, copper samples from sources in Balochistan, Oman and Iran form a linear swath of datapoints that plot across the isotope fields defined by lead samples from those same regions (and southern Afghanistan too if the Mundigak ores are used as proxy source samples). This illustrates the point I tried to make at the conclusion of the section on lead and silver – as more samples from more deposits across these regions are incorporated the database, there is almost certainly to be a significant degree of isotopic overlap between them. Perhaps with high precision TIMS measurements the sources in this part of the plot can be differentiated from one another but that is by no means certain. For metal artifacts from Indus Valley sites having Pb isotope characteristics that cause them to plot in this area it may, ultimately, only be possible to state that they probably came from sources to the west of the Indus Valley or from Oman.

## CHAPTER CONCLUSION

The Pb isotope measurements produced using the ICP-MS at the LARCH are, admittedly, not as accurate as those obtainable using TIMS or MC-ICP-MS. However, they are accurate enough to differentiate lead and copper ores sources as isotopically diverse as those found in and around the Greater Indus region. Moreover, because of the ease of sample preparation and non-destructive nature of the EDTA sampling technique, many artifacts were assayed that would otherwise be unavailable for analysis. In addition, the comparatively low cost of analysis means that large numbers of artifacts and, importantly, comparative geologic samples could be assayed.

Much work remains to be done to create comprehensive Pb isotope databases with which to evaluate the potential lead and copper geologic provenience of artifacts from Harappa and other archaeological sites in the region. With regard to sources that may have been utilized by Indus Civilization peoples, there are many deposits in the study regions that remain uncharacterized. There is currently no isotopic data for any metalliferous ore bodies in Afghanistan. The need to assay the lead deposits of Haraza, NWFP and copper deposits in Jammu and Kashmir is particularly acute as I have provided evidence in this chapter and elsewhere in this book that Harappans were probably acquiring several rock and mineral varieties from these regions to the north of the site. One area, which I have not previously discussed in this chapter, where both lead and copper mineralization have been reported (Heron and Crookshank 1954 95-96; Siddiqui and Shams 1988: 3), is eastern portion of the Salt Range, just 230 km north of Harappa. This is, in fact, the source area *nearest* to the site for either of those metals! The copper mineralization is said to be trifling but the galena occurrences were apparently popular sources of surma for the local population (Punjab Government 1907: 204; Wynne 1878: 300-301). Obtaining and analyzing samples from this region is of the highest priority and their absence in the databases is another reason why the geologic provenience determinations made in this chapter should always be considered provisional.

In addition to expanding the databases to incorporate new sources, it will be equally important to produce many more assays on the deposits already

in it. Currently, the average number of analyses per source is around five. It is generally held that at least 20 analyses of a lead ore field need to be conducted in order to adequately define its isotopic boundaries (Pollard and Heron 1996: 328). Still others have argued that having a bare minimum of 40 analyses is more realistic, especially when the isotope data for an ore field are not normally distributed (Baxter *et al*. 2000). By those standards some sources in this database, such as the Rajpura-Daribia/Rampura-Agucha lead ore field, which has 31 data points, are fairly to very well characterized. Nearly all other sources in it are dramatically under-characterized, with several even being represented by only a single data point. Even at this early stage, however, a great deal new has been learned with regard to the lead, silver and copper acquisition networks in which the residents of Harappa, as well as some of their predecessors and contemporaries at sites in the Greater Indus region and beyond, were involved.

We now know that residents of Harappa were acquiring raw lead ore (galena) from the Jammu and Kashmir region at the time of the site's foundation (Ravi Phase) and were still doing so during the latter part of the urban phase (periods 3B and 3C). They apparently used some of the lead from this source to make surma. Residue in a surma bottle from Mohenjo-daro suggests residents of that site used lead from a different (unknown) source to make this cosmetic. During Period 3C, Harappans also appear to have been acquiring raw lead from at least two (possibly more) other regions. Cerussite-anglesite and massicot ores from sources in southern Balochistan (the deposits near Sohr Damb/Nal in the Khuzdar district are the strongest candidates) were probably used as mineral pigments or cosmetics. Some of the lead used by Indus peoples at Mohenjo-daro, Dholavira, Rakhigarhi, and Gola Dhoro, as well as the early residents of Mehrgarh, also came from occurrences in that region. Harappans acquired lead from at least one or more additional sources, the locations of which are not known at this time. These unknown sources do not appear to be the same ones that residents of the Helmand Civilization sites of Mundigak and Shahr-i-Sokhta probably exploited in southern Afghanistan and east Iran. Harappans melted lead from all three regions (Jammu and Kashmir, southern Balochistan and the unknown source or sources) to fashion various kinds of items.

It appears that the silver used by Indus Civilization peoples was being extracted from at least three, possibly more, different argentiferous lead ore sources. The Early Harappan settlers of Nagwada may have brought this metal with them from deposits in southern Balochistan (probably around Khuzdar) as they moved into northern Gujarat from regions to the northwest. The silversmiths who created the artifacts in the Allahdino hoard seem to have used some metal from deposits in that region as well. They also appear to have used metal from the same source(s) as those who made the silver artifacts analyzed from Mohenjo-daro. The location of that source is presently unknown, however. The silver/lead used to make a ring from the site of Gola Dhoro may have originated in eastern Arabia. Further studies of potential sources in that region need to be conducted in order to confirm this, however.

Finally, we now see that residents of Harappa did not acquire a great deal of raw copper ore (malachite or chalcocite). Only seven examples have been recovered at the site to date. Most of these (5 or 6 of the 7) were probably derived from sources to the west of the Indus Valley or, perhaps, Oman. One ore fragment may have come from deposits in the northern part of Rajasthan's Aravalli Range. Recent research (Hoffman and Miller 2009) suggests that finished copper alloy objects, which constitute a major part of Harappa's rock and mineral assemblage, might follow a pattern similar to that of the ores. This situation might be very different at the southernmost Indus city of Dholavira, however. Preliminary results indicate that site residents were acquiring much of

their copper (as well as some lead) from deposits occurring in northern Gujarat near Ambaji.

In the next chapter, I take the provenience determinations made for all of the lead artifacts and copper ores from Harappa and, together with the determinations made for each of the other materials examined in the preceding seven chapters, address the three lines of inquiry outlined in Chapter 1.

# CHAPTER 13

# SUMMARY AND DISCUSSION

## CHAPTER INTRODUCTION

The principal research objective of this study was to locate the geologic sources of the rock and mineral resources acquired by the ancient residents of Harappa. In Chapter 4, the site's entire stone and metal artifact assemblage was categorized into material varieties and then, using recent field observations and contemporary geologic reference materials (as opposed to century-old District Gazetteers), the most probable sources for the majority of them were outlined. Throughout the eight chapters that followed, selected varieties were directly compared to geologic samples collected from potential sources using a range of analytical methods. Over 2100 provenience determinations for artifacts from Harappa[1)] were generated as well as almost 120 for artifacts from other sites. In this chapter, these data are summarized and brought to bear on the three lines of inquiry outlined in Chapter 1. The implications of the answers to those inquiries are discussed in the concluding section.

## SUMMARY

The results of this study are summarized in a series of maps on which symbols for identified and probable rock and mineral sources are plotted for each chronological period and sub-period at Harappa. When this is done, six detailed "pictures" (figures 13.2 through 13.7 corresponding to Harappa periods 1, 2, 3A, 3B, 3C and 4/5) emerge that approximate the extent of Harappan rock and mineral resource acquisition at different periods in time. Provenience data for artifacts from the other sites examined are




**Figure 13.1** Key for figures 13.2 to 13.8.

1) Grindingstone (n = 1796), chert (n = 24), steatite (n = 141), agate (n = 24), vesuvianite-grossular (n = 7), limestone (n = 113), alabaster (n = 30), lead and copper (n = 36). *Total* = 2170.

summarized on Figure 13.8.

Figure 13.1 is the key for the maps. All rock and mineral varieties recovered from secure contexts at Harappa and the symbols representing them are listed. A symbol for silver, which appears only on the figure (13.8) detailing acquisition networks for other sites, was added to the key. On the maps themselves, resource acquisition is depicted with varying degrees of confidence. Solid lines from source symbols to sites denote acquisition networks based on firm provenience data. For example, the solid lines between the Rohri Hills chert source and Harappa drawn on the maps for periods 1 through 3B (figures 13.2 to 13.5) indicate that for each period at least one artifact was compared to samples from various chert sources and assigned to the Rohri Hills. Dashed lines depict networks that can still be reasonably inferred to have existed even though provenience data was not generated. For instance, although no tan-gray chert artifacts from Period 3C levels were analyzed, a dashed line was drawn from Harappa to the Rohri Hills for that period (Figure 13.6) based on the fact that identical looking artifacts from all previous periods were assigned to that source. The pathways of all network lines are, of course, conjectural. When possible, line thicknesses were varied in order to approximate differential source use among certain varieties (recall on p. 254 how this was done for steatite). Symbols plotted alone (without network lines) denote sources that are argued – based solely on factors such as the extent of the culture phase that Harappans belonged to and the overall acquisition pattern, to have *perhaps* been utilized during particular periods. All statements made in the summaries below are based on data and other evidence presented in previous chapters.

## Ravi Phase – Period 1 (ca. 3300 BC to 2800 BC)

No fewer than 14 rock and mineral varieties were brought to Harappa during the Ravi Phase (Figure 13.2). Steatite was obtained from sources in two regions – Jammu and the northern Aravalli Range. Although some chert was acquired from the Rohri Hills of Sindh and the west-central Salt Range, at this time a purple-hued chert-chalcedony that *perhaps* originated in areas of trap rock in the eastern Salt Range and/or Kashmir was mainly used. The majority of the grindingstones recovered came from the relatively nearby Kirana Hills. Only small amounts of the stone used to make querns and mullers came from the much more distant Sulaiman Range, Himalayan Foothills (Siwaliks) or the outliers of the Aravalli Range in southern Haryana. The sole Ravi Phase galena fragment recovered was derived from one of the lead deposits in the Jammu and Kashmir region. The one vesuvianite-grossular artifact (a flake) found came from an occurrence in the Mohmand Agency. Because the only viable lapis lazuli sources for Harappans would have been the Badakhshan deposits of northern Afghanistan, it can be very confidently stated that all lapis lazuli artifacts recovered from this phase (and subsequent ones) came from that region.

Provenience analyses have not been conducted on any of the remaining rock and mineral varieties recovered from Period 1. It is, however, reasonable to assume that many of them came from the same regions to the north of the settlement that Ravi Phase Harappans acquired (and from which Harappans of later phases would continue to acquire) a large portion of their raw stone and metal. Alabaster from Period 1 levels was probably derived from the same sources in the Salt Range used during periods 2 and 3. Gold was likely obtained from the rivers draining the Himalayas, which were the nearest sources and no doubt then much richer. Amazonite and almandine garnet may have come from Himalayan pegmatites along with igneous/metamorphic rocks. Some rocks of the latter variety, as well as ochre minerals, probably also came from the much closer Kirana Hills.

Copper might have come from one of the minor

occurrences in the western Himalayas. However, they may also have been acquired from sources in other regions. The presence of steatite from the northern Aravalli Range opens the possibility that the rich copper resources of that region were accessible at this time. Additionally, some igneous and metamorphic rocks might have come from the Tosham Hills, which lie in the direction of the Aravallis. The presence of marine shell from the Arabian Sea coast during the Ravi Phase (Kenoyer and Meadow 2000: 67) suggests that the agate and, possibly, the amazonite sources of distant Gujarat may have also been accessible at this time.

### Kot Diji Phase – Period 2 (2800 to 2600 BC)

Harappans acquired at least 14 varieties of rocks and minerals during the Kot Diji Phase (Figure 13.3). Steatite was now obtained exclusively from sources in regions to the north of the site – mainly from Jammu and the Hazara District of the NWFP but also from the Khyber and Kurram agencies. The majority of the chert used at this time still came from the west-central Salt Range. However, increasing amounts were being acquired from the Rohri Hills and some *may* have been brought from the Mohmand Agency. The use of purple-hued chert-chalcedony was diminishing. Most querns and mullers were still being made from Kirana Hills stone. There was a slight increase in the amount of Pab sandstone from the Sulaiman Range being used to make grindingstones but materials from the Himalayan Foothills and the Aravalli outliers were still only acquired in very minor amounts. Alabaster was derived from sources in both the central and western Salt Range. At least some agate was acquired from a source (Mardak Bet) in northern Gujarat.

The likely sources for the remaining Kot Diji Phase rock and mineral varieties are, with a few additions, mostly the same as they were during the Ravi Phase. The limestone that first appears in Harappa's assemblage at this time is an extremely commonplace type (brown micritic). It might have come from the Salt Range along with chert and alabaster-gypsum. Or it could be from the Sulaiman Range or Rohri Hills. The situation is the same for quartz and rock crystal artifacts. Those may have come from the Kirana Hills or they could be from sources further a field. The broader cultural horizons of the Kot Diji Phase would have made many resources in distant regions, such as the copper deposits of western Balochistan (Chagai Hills area), much more accessible to residents of Harappa.

### Harappa Phase – Period 3A (2600 to 2450 BC)

The twelve rock and mineral varieties recovered from the limited exposures of Period 3A levels (Figure 13.4) almost assuredly do not represent the full range of stone and metal resources acquired at that time. They do, nonetheless, provide evidence that some changes in acquisition patterns took place (or were taking place) around the time fully urban lifeways emerged at Harappa. The primary regional source of steatite was now (and would hereafter be) the Hazara District of the NWFP. Minor amounts of that stone were acquired from deposits in Jammu and the Khyber Agency as well as, for the first and only time, the Las Bela ophiolite of southern Balochistan. The serpentine artifacts that initially appear in Harappa's assemblage during this phase may have also come from the latter region or another with a similar geology (e.g., the Zhob, Muslimbagh or Mohmand area ophiolites). The Rohri Hills of Sindh appear to have been the sole chert source used by site residents at this time. Pab sandstone from the Sulaiman Range now slightly surpassed Kirana Hills stone as the most acquired type of raw material for making querns and mullers. There were also slight increases in the use of grindingstone from the Himalayan Foothills and northern Aravalli outliers. Agate (carnelian) was likely obtained from sources in Gujarat, just as it was in the periods that proceeded and followed this one.

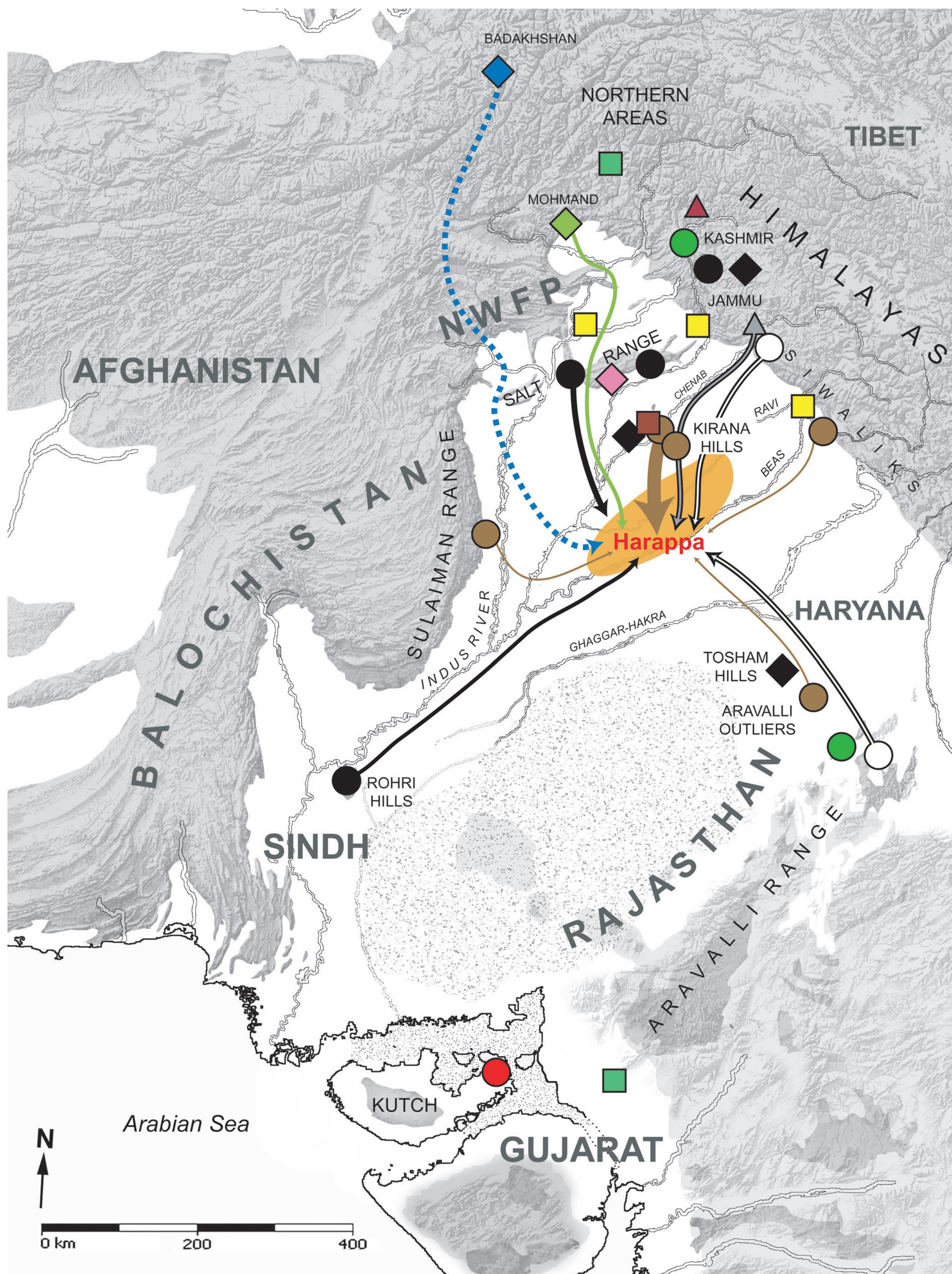



**Figure 13.2** Harappa's rock and mineral sources and acquisition networks.
Period 1 –Ravi Phase (ca. 3300-2800 BC). Yellow shaded area indicates the approximate extent of the Ravi Phase.

The isotopic characteristics of some of the alabaster artifacts from this period (and from periods 3B and 3C) suggest that they *may* have come from unanalyzed sources in Jammu and Kashmir.

### Harappa Phase – Period 3B (2450 to 2200 BC)

Harappans were acquiring at least 19 rock and mineral varieties by the middle part of the urban phase – Period 3B (Figure 13.5). The Haraza District was again the primary source for steatite but some was also brought from Jammu, the Khyber and Kurram agencies and the northern Aravalli Range. Although most of the chert used at Harappa still appears to be from the Rohri Hills, there are indications that some *may* have been obtained from the Mohmand Agency, NWFP. This is certainly possible as vesuvianite-grossular was also being acquired from a source in that region. The lead in a lead-based cosmetic from a Period 3B burial came from a source in Kashmir, perhaps in the Buniyar area. The use of Kirana Hills stone for querns and mullers practically ceased during this phase. Although the acquisition of stone from the Himalayan Foothills and northern Aravalli outliers increased slightly over the preceding period, the majority (nearly 70%) of grindingstone was still brought from the Sulaiman Range. Agate was being obtained from two sources in northern Gujarat – Khandek in western Kutch and Mardak Bet in the Little Rann. Some *may* have also come from same sources used by residents of Shahr-i-Sokhta, which would most likely have been in the Helmand region or western Balochistan.

The recovery of Mari "Diamonds" – the bi-pyramidal quartz crystals that occur within certain massive gypsum deposits of the Salt Range, from Period 3B levels indirectly suggests that alabaster from that region was being acquired at the time. "Ernestite" first appears in Harappa's assemblage during this period and, although no occurrences of the stone have yet been located, the fireclay beds of Kutch in northern Gujarat are among the best candidates for sources. Turquoise, which most likely came from western Tibet and/or Central Asia, also makes its first appearance at this time. Finally, if the distinctive spinach-green nephrite amulet from a Period 3B burial is quite likely from Siwalik conglomerate beds in the Kohat District, NWFP.

### Harappa Phase – Period 3C (2200 to 1900 BC)

By the latter part of the urban phase – Period 3C, Harappans were acquiring 22 different rock and mineral varieties (Figure 13.6). The Haraza District, NWFP was once again the primary source for steatite. Small amounts were also being brought from deposits in the Khyber and Kurram agencies and the northern Aravalli Range but, for the first time, not from Jammu. Although Pab sandstone from the Sulaiman Range remained the most acquired type of grindingstone during Period 3C, its use decreased somewhat while there were increases in the amounts of raw material brought from the three other major sources. Vesuvianite-grossular was now obtained from sources in two regions – the Mohmand Agency and the southern Zhob District (Muslimbagh ophiolite) of Balochistan. Alabaster was derived from sources in the western Salt Range (along with Mari "Diamonds"), Kohat, multiple sources across the Loralai / Sulaiman Range area of northern Balochistan and, perhaps, Jammu and Kashmir. Harappans were acquiring lead from deposits in Jammu and Kashmir as well as from sources in the Las Bela and Khuzdar districts of southern Balochistan. Various types of limestone were obtained from northern Kutch, the Rohri Hills, the Jaisalmer area of Rajasthan and, probably, the Loralai area of Balochistan. Agate was being acquired from at least three sources across Gujarat – Khandek, Mardak Bet and, now, Ratanpur in the southern part of the state. Finally, a malachite fragment from this period appears to be related to the copper deposits of the northern




**Figure 13.3** Harappa's rock and mineral sources and acquisition networks. Period 2 –Kot Diji Phase (ca. 2800-2600 BC). Yellow shaded area indicates the approximate extent of the Kot Diji Phase.

Aravalli Range.

Although no artifacts from this sub-phase were analyzed, most chert used during Period 3C was probably still acquired from the Rohri Hills. Of the new materials in the assemblage, prehnite likely came from the Las Bela or Muslimbagh ophiolites, fluorite from the Kalat District of Balochistan, mica from the Northern Areas and fossil foramina from the Sulaiman Range.

### Transitional and Late Harappa Phase – Periods 4 & 5 (ca. 1900 to <1300 BC)

Only 12 rock and mineral varieties have been recovered during excavations of the poorly preserved transitional and Late Harappa Phase levels – periods 4/5 (Figure 13.7). They do, however, indicate that northern interaction networks persisted into Harappa's late/post-urban phase. Steatite was being acquired from the Hazara District and the Khyber Agency; vesuvianite-grossular was brought from the Mohmand Agency; and lapis lazuli from northern Afghanistan evidently remained obtainable. No analyses of agate or chert from periods 4/5 levels were conducted so it is impossible to say whether or not those materials were still being brought from Gujarat and Sindh (respectively). Both, however, could have come from regions to the north. Agate sources, although remote, do exist in the western Himalayas and there are indications from prior periods (2 & 3B) that chert from the Mohmand Agency was sometimes brought to the site. On the other hand, agate sources to the southeast, in the Malwa Plateau region, might been more accessible during this phase. The kaolinite claystone used to make a bead found in a cache from this period could have come from many regions but the strongest and nearest possibilities are found to the north of Harappa in the Salt Range and NWFP.

A strengthening of acquisition networks extending toward regions southeast of Harappa is indicated by the grindingstone assemblage of the Late Harappa Phase. Whereas Pab sandstone from the Sulaiman Range had dominated this material sub-assemblage throughout Period 3, fewer than 10% of the querns and mullers recovered from periods 4/5 levels are made from it. Delhi quartzite from the Aravalli Range outliers in southern Haryana had, for the first time, become the single most acquired type of grindingstone. The use of stone from the Kirana Hills was also up significantly over the preceding period.

### Provenience data from other prehistoric sites – seventh to third millennium BC

Steatite, chert, grindingstone, agate, vesuvianite-grossular, alabaster, lead and silver artifacts from around two dozen additional sites were geochemically analyzed or visually examined for this study. The resulting provenience data provide a valuable supplementary perspective (Figure 13.8) with which to contextualize and interpret the results from Harappa.

Data from the analysis of steatite artifacts from seven sites were presented in this book. Observations and the preliminary results from ongoing studies at several additional sites were summarized. These studies have revealed both regional differences and similarities in the acquisition and use of this variety of stone. Residents of Neolithic to early Chalcolithic (ca. 7000 to 5000 BC) Mehrgarh used both dolomitic and ultramafic steatite from sources in Balochistan. Much later, peoples who lived at the nearby Harappan town of Nausharo acquired ultramafic steatite from the Las Bela area deposits of southern Balochistan. The distinctive appearance of an unfired bead from Balakot suggests that Harappans at that site were also exploiting locally (to them) available raw material from the Las Bela deposits. In Gujarat, the Harappans of Nagwada, Gola Dhoro and Dholavira utilized ultramafic steatite, which they obtained from sources in southernmost fringes of the Aravalli Range. Ultramafic steatite cannot be fired white, however. It was probably for this reason

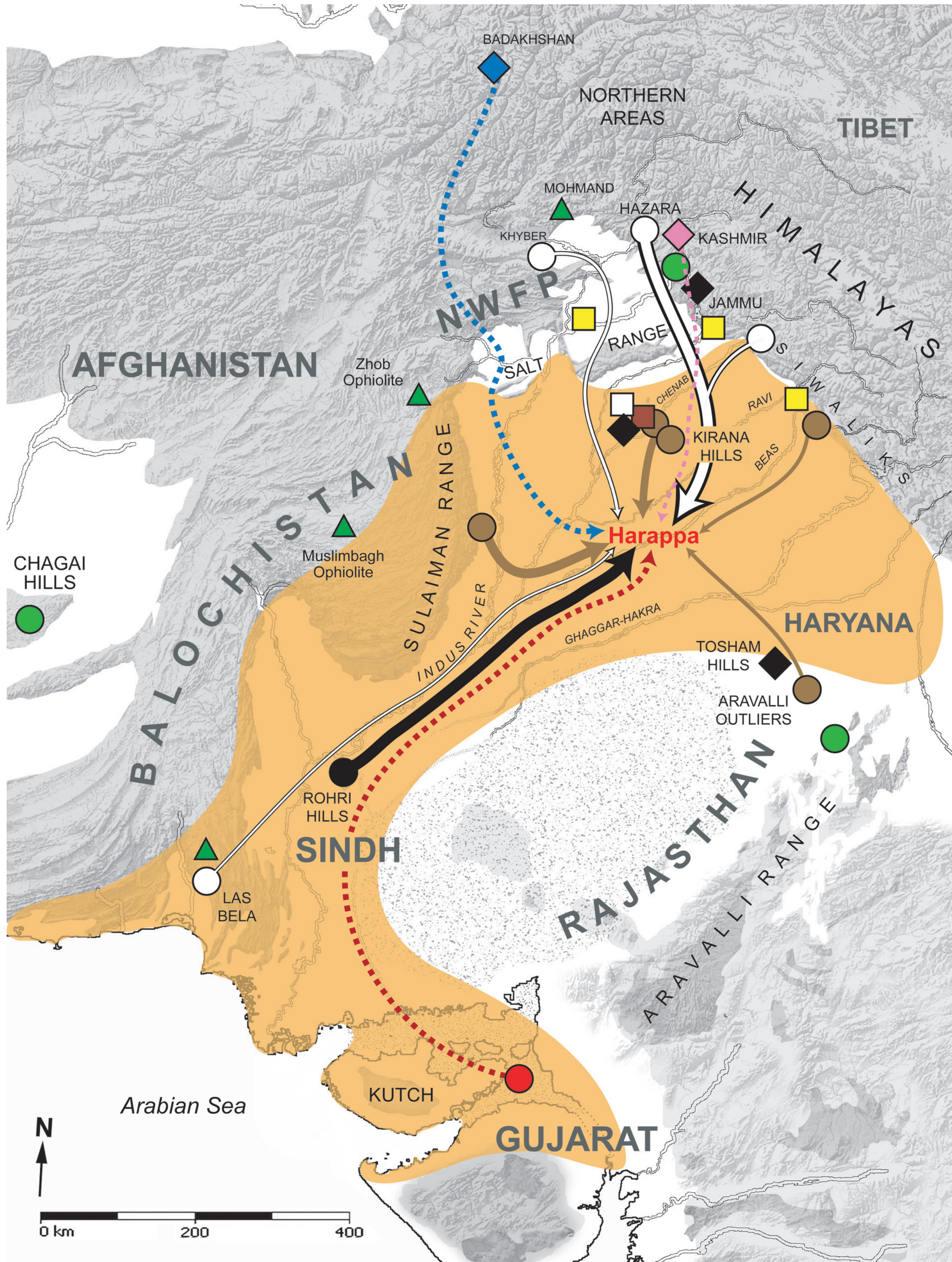



**Figure 13.4** Harappa's rock and mineral sources and acquisition networks. Period 3A –Harappa Phase (ca. 2600-2450 BC). Yellow shaded area indicates the approximate extent of the Harappa Phase.

that consumers at the Indus cities of Mohenjo-daro, Dholavira, and Rakhigarhi mainly used white-firing dolomitic steatite from the very same northern sources favored by residents of Harappa. Alternate dolomitic sources were sometimes exploited. Steatite of this type from northern Rajasthan was used at Mitathal, Mohenjo-Daro and, to a minor degree, at Harappa. Interestingly, steatite artifacts from the site of Tepe Hissar in Iran were also found to be of dolomitic origin.

Much was learned about patterns of chert acquisition in ancient South Asia from the examination of museum collections and site surface observations. Early Harappans living at settlements in Bannu Basin and Gomal Plain were using radiolarian chert/jasper from the nearby of Zhob and Waziristan ophiolites that, although often colorful, was clearly not the same as the purple chert/chalcedony used by their contemporaries at Harappa. On the other hand, the black-brown chert from periods 1 and 2 levels at Harappa, which was determined to have originated in the Sakesar Formation of the Salt Range, was apparently also acquired by Early Harappans at Rehman Dheri on the Gomal Plain; at Musa Khel on the southern side of the Salt Range next to the source; and at Hathial on the northern margin of the Potwar Plateau. This regional black-brown chert distribution network evidently gave way (at least at Harappa) to the extra-regional distribution of tan-gray chert from the Rohri Hills of Sindh. The highly distinctive banded type of Rohri Hills chert was observed on the surface at and/or in excavation collections from each of the major Indus Civilization cities as well as smaller Harappan sites such as Allahdino and Chanhu-daro. Using INAA, tan-gray chert samples from Nagwada, Dholavira and Rakhigarhi have been analyzed and found, in most instances, to be closely related to geologic samples from the Rohri Hills.

Querns and mullers from a dozen Early Harappan and Indus Civilization sites were examined (in collections and on site surfaces) using the same macroscopic criteria that were employed to assign geologic proveniences to grindingstone artifacts at Harappa. These observations, although limited, are beginning to reveal the extents of the various regional bulk stone transportation networks to which residents of Harappa had access. We see that, as it was moved west toward Harappa, Delhi quartzite from the Aravalli Range outliers was dispersed to settlements like Mitathal, Siswal, Rakhigarhi, Banawali and Kalibangan. Like at Harappa, the gray sandstone observed at Banawali was probably brought from the Siwalik Foothills to the site via the waterways (in Banawali's case the Ghaggar River) draining that region. In the western Punjab, stone from the Kirana Hills was transported south beyond Harappa to sites along the lower reaches of the old Beas River bed. Pab sandstone from the Sulaiman Range was also observed at the Beas sites as well as to the south at Ganweriwala in Cholistan, to the north at Ghandi Umar Khan on the Gomal Plain and as far east at Rakhigarhi in Haryana. A great many (perhaps the majority) of the querns and mullers at Mohenjo-daro also appear to be made from Pab sandstone. Those, however, were most likely acquired from the continuation of the Pab Formation in southern Balochistan. Most of the grindingstones from Dholavira appear to be composed of locally or regionally sandstone.

Agate artifacts from Chalcolithic phase Mehrgarh and the Harappan Period sites of Nagwada, Dholavira, Chanhu-daro, Mohenjo-daro, Nausharo and Rakhigarhi have been compared to geologic samples from three agate sources in Gujarat and agate debris fragments from the proto-historic site of Shahr-i-Sokhta in Iran (which served as proxy samples for an Iranian agate source). As at Harappa, most of the artifacts resembled one of the Gujarat sources. A few from Mehrgarh and Nausharo did appear to be more closely related to the Shahr-i-Sokhta agates, which was not particularly surprising as those sites are located along the major transit way connecting the Indus Valley to highland Balochistan and, eventually,




**Figure 13.5** Harappa's rock and mineral sources and acquisition networks. Period 3B –Harappa Phase (ca. 2450-2200 BC). Yellow shaded area indicates the approximate extent of the Harappa Phase.

eastern Iran. Interestingly, two of the analyzed fragments from Chanhu-daro were also more closely related to the Iranian agates than to the Gujarati sources. Although they could be from Iran they may actually be from a poorly known agate occurrence in nearby Sindh Kohistan.

Vesuvianite-grossular fragments from Mohenjo-daro were determined to have originated in the same two source areas from which beadmakers at Harappa acquired that stone – the Sakhakot-Qila ophiolite in the Mohmand Agency and Muslimbagh ophiolite in northern Balochistan. Acquisition networks for finished vesuvianite-grossular items seem to have extended south to Gujarat, where ornaments made from the stone (but not manufacturing debris) have been identified at Dholavira and Lothal.

Alabaster fragments from the Kot Dijian / Late Kot Dijian Phase settlements of Rehman Dehri and Musa Khel were found, not surprisingly, to have been derived from nearby sources in the Salt Range. Both sites were, quite possibly, places where this variety of stone and other resources from the region (such as black-brown Sakesar chert) were gathered before being transported to Harappa. An alabaster vessel fragment from Mohenjo-daro could not be attributed to occurrences in the Salt Range or to any of the other sources examined. That item *may* represent an import from outside of the Greater Indus region.

Raw lead and/or lead metal from the deposits of southern Balochistan was traded widely. It has now been identified not only at Harappa in the Punjab but also at Mehrgarh and Nausharo in central Balochistan, Rakhigarhi in Haryana, Mohenjo-Daro in Sindh, and Dholavira and Gola Dhoro in Gujarat. There are indications that lead from these deposits was traded as far away as Ra's al-Hadd in Oman and Mundigak in southern Afghanistan. Residents of the latter site likely obtained some galena from nearby Asad Qala as well, although it is difficult to know with certainty until that and other lead deposits in Afghanistan are isotopically assayed. A handful of lead artifacts from Dholavira come from the Ambaji area of northeastern Gujarat while a few galena fragments from Mehrgarh appear to be from a source to the west, perhaps in the Chagai Hills region. Lead residue in a small bottle recovered from that site could not be attributed to any of the sources examined in this study, however.

To date, silver artifacts from seven sites have been assayed and compared to isotopic data from argentiferous lead deposits in the Greater Indus region and Iran. Nine of ten silver items from the Harappa Phase Allahdino jewelry hoard were found to be isotopically analogous to argentiferous lead deposits in the southern Balochistan region. A silver ring fragment from Early Harappan levels at Nagwada as well as multiple ornaments from Dholavira and Rakhigarhi were likewise found to have probably come from that same source area. All silver artifacts analyzed from Mohenjo-daro, as well as one from Allahdino, could not be confidently assigned to any of the deposits to which they were compared. These items *may* represent imports from outside of the Greater Indus region. A silver-lead ring from Gola Dhoro might well be from a source in eastern Arabia and although the lead in a silver ring from Mundigak is analogous to a deposit in northern Pakistan (Chitral), it is more likely to have come from an unassayed source in Afghanistan.

## ADDRESSING THE THREE LINES OF INQUIRY

Informed by the synchronic "pictures" of Harappan rock and mineral acquisition presented in the preceding section, the three lines of inquiry pursued in this study are addressed one final time, beginning with: *With whom in the Greater Indus region or beyond were the residents of Harappa interacting, either directly or indirectly, when they acquired rock and mineral resources? What was the extent of those inter-regional relationships/resource*

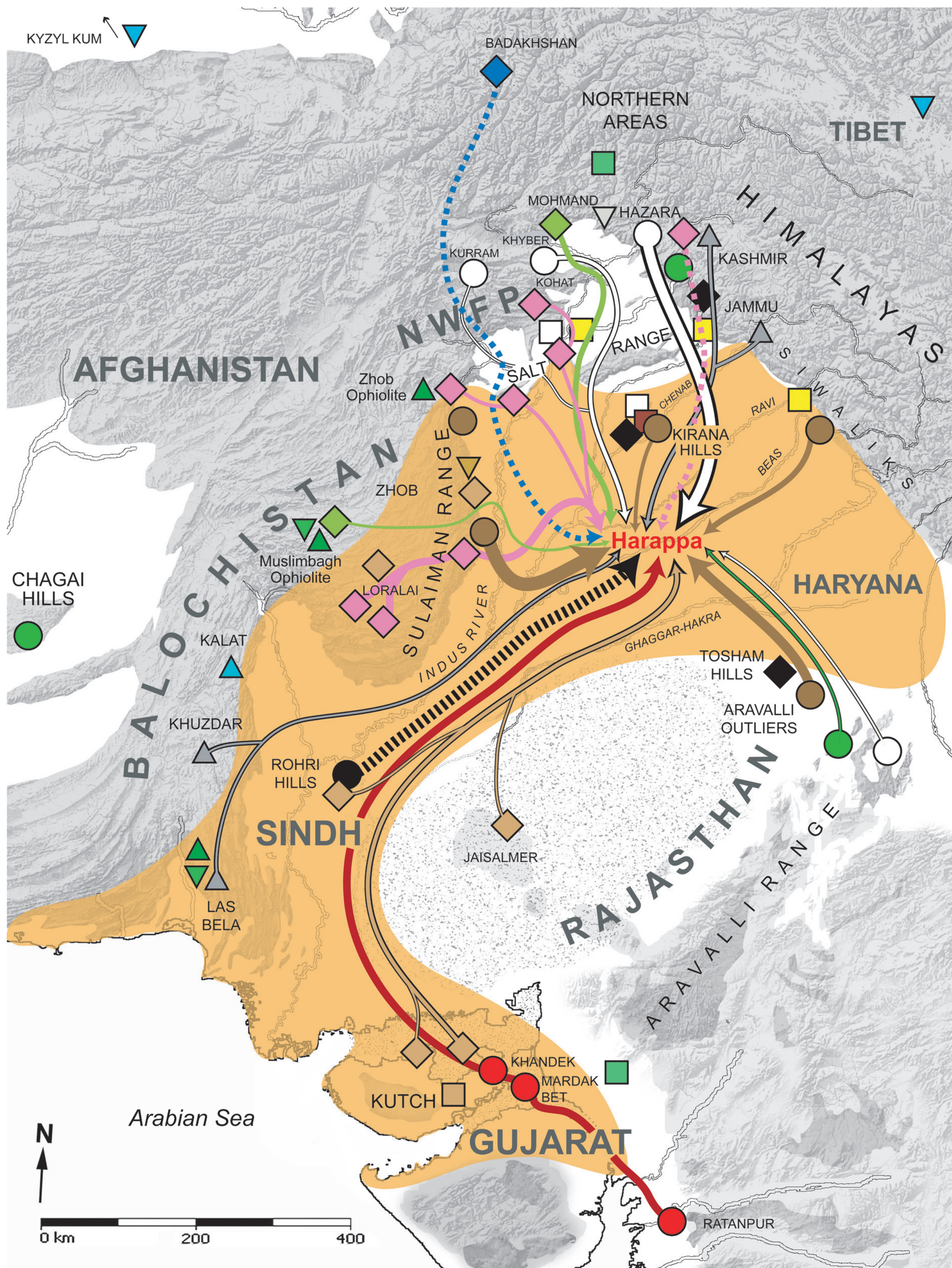



**Figure 13.6** Harappa's rock and mineral sources and acquisition networks. Period 3C –Harappa Phase (ca. 2200-1900 BC). Yellow shaded area indicates the approximate extent of the Harappa Phase.

*acquisition networks during different periods in time?*

Rock and mineral artifact provenience determinations indicate that residents of Harappa "interacted" (recall the discussion of this term on pp. 24-25) with peoples in most every major region in and around the Indus Basin at one time or another. As those regions and the cultural phases associated with them are identified below, it may be helpful to refer back to the maps (Figure 2.6 A to D) and overviews (pp. 42-48) presented in Chapter 2.

In order to have acquired a substantial portion of the stone and metal items they possessed, Harappa's residents of all periods had to have been interacting with peoples that dwelled (either permanently or periodically) in regions to the north of their settlement. During periods 1 and 2, some of those northern peoples would have been other Early Harappans – other Ravi Phase peoples in the Rechna Doab; Tochi-Gomal Phase peoples in the Bannu Basin and Gomal Plain regions; and other Kot Dijians across all of those areas and up to the northern Potwar Plateau. Period 3 residents would have been interacting with "Late" Kot Dijians in those same areas as well other Harappans dwelling at least as far north as the Himalayan foothills, the southern flank of the Salt Range and the Gomal Plain. Beyond this the picture of interaction is less clear. Some degree of contact with Northern Neolithic peoples almost certainly took place during both the Early Harappan and Harappan periods when site residents acquired stone and metal from the Kurram, Khyber, Mohmand, Malakand, Hazara, Jammu and western Kashmir regions. Although Northern Neolithic sites have not yet been discovered in the immediate vicinity of the sources identified in those areas, they are found in the nearby Swat and Kashmir valleys as well as the northern Potwar Plateau. Rock and mineral provenience determinations indicate that residents of Harappa continued to interact with the proto-historic peoples in many of those same areas during the Late Harappan (Cemetery H) Phase. Lapis lazuli artifacts unequivocally demonstrate a link with northern Afghanistan during all periods at Harappa. Who might have been present at that acquisition network's point of origin (no doubt for only a short portion of the year given its extremely high elevation) is unknown, however.

Rocks and minerals determined to have come from sources in the Sulaiman Range and northern Balochistan reflect interaction between residents of Harappa and their fellow Early Harappans (Kot Dijians) and Harappans in regions to the west. Grindingstones from the Kaliana Hills of southern Haryana demonstrate links with Early Harappan (Sothi-Siswal Phase), Harappan and Late Harappan (Cemetery H) peoples to the east. Stone and metal goods and resources from Sindh, Gujarat and southern Balochistan point to interaction with other Early Harappans (Hakra Phase peoples from Cholistan to northern Sindh during Period 1 and Kot Dijians dwelling as far south as Sindh Kohistan and, perhaps, the northern Gujarat region during Period 2) and Harappans in the southern reaches of the Greater Indus region. Lead artifacts from the Khuzdar region suggest some degree of interaction with Kulli Phase peoples of southern Balochistan during Period 3C at Harappa.

Evidence for interaction between residents of Harappa and the ancient peoples of Rajasthan exists but is limited. The handful of steatite artifacts (p. 238) and the single copper ore fragment (p. 456) tentatively assigned to sources in the northern part of that state would seem to indicate that interaction with Malwa-Rajasthan Tradition peoples (Ganeshwar-Jodhpura Phase) took place during the Early Harappan and Harappan periods. Some limestone appears to have been brought to Harappa from the Jaisalmer area of Rajasthan during Period 3C. It is unknown, however, who inhabited that region at the time.

Before continuing it is important to again acknowledge that stone and metal artifact provenience




**Figure 13.7** Harappa's rock and mineral sources and acquisition networks. Period 4/5 – Transitional & Late Harappa Phase (ca. 1900 to <1300 BC). Yellow shaded area indicates the approximate extent of the Cemetery H Phase.

data alone does not and can not capture the full scope of Harappan inter-regional relationships. Other lines of evidence – material (ceramic, shell, faunal, botanic), stylistic/iconographic and written (in contemporaneous Mesopotamia), indicate that Early Harappans and/or Harappans had connections with (and sometimes even dwelled in) distant regions from which it has not yet been demonstrated that rock and mineral goods or resources were being acquired. Some of these types of evidence are taken into account as I next consider the extent of inter-regional interaction/acquisition networks during different periods at Harappa and the degree to which they can be characterized as being external or internal to the successive cultural phases to which site residents belonged.

The presence of Rohri Hills chert and lapis lazuli in Period 1 levels shows that Ravi Phase residents of Harappa acquired stone from as far south as northern Sindh and as far north as northern Afghanistan. However, the marine shell also found in those levels (Kenoyer and Meadow 2000: 67) indicates that southern interaction networks for that phase actually extended to the Arabian Sea. Ravi Phase settlements are currently known only to exist along middle and lower reaches of the Ravi River in the western Punjab. Therefore, apart from those materials attributable to the Kirana Hills, all rocks and minerals acquired by Harappans during Period 1 would have come to the site through external trade networks.

Shaffer's statement (1982: 192) that "with the exception of turquoise and lapis lazuli" all raw materials used to make the objects found at Indus Civilization sites occur "within the distribution area of the Harappan culture in the Greater Indus Valley," is true. It is mostly true of the preceding Kot Diji Phase as well. This does not necessarily mean, however, that all stone and metal goods and resources (save for turquoise and lapis lazuli) acquired by periods 2 and 3 residents of Harappa actually came from occurrences within the areas that peoples of their respective phases occupied. For example, minor instances of copper mineralization are found sporadically across the Greater Indus region. The nearest to Harappa (noted as #4 on Figure 4.13 in Chapter 4) is located in the Salt Range (Shah 1980: 99). However, that instance and most others like it (including the small occurrence in Waziristan assayed in Chapter 12) exhibit no evidence of ever having been worked and could not have yielded a substantial amount of metal even they had been. The closest sources that could have provided Harappans copper in the quantities they used all occur in areas external to the Indus Civilization (i.e. western Balochistan, northern Rajasthan and Oman). A somewhat similar situation exists for steatite. Although occurrences of the stone are fairly widespread, sources of raw material having the qualities that Harappans sought (workability and turning white when heat-treated) are few and relatively far a field.

In order for Kot Dijian and Harappan phase peoples to have acquired certain stone and metal resources in the quantities they used and with the qualities they sought, it would have been necessary for them to have had access to sources outside of the areas (noted as the solid orange shaded areas on figures 13.3 through 13.6) across which they are presently known to have dwelled. That being said, most of the raw material sources that have been identified are located immediately adjacent to those areas. Some of them, such as the copper and steatite deposits of the northern Aravalli Range, lay in regions that were clearly occupied by non-Kot Dijian/Harappan peoples and so can be confidently characterized as external to those phases. However, the cultural associations of many others, especially those along the northern and western margins of the Greater Indus region, are much less clear. Most maps in this book were made in a style (with lines or shaded areas demarcating the approximate extents of cultural phases) that creates the somewhat misleading impression that the cultures depicted on them were




**Figure 13.8** Rock & mineral acquisition networks for other prehistoric sites (ca. 7th to 3rd millennium BC).

homogenous and well-bounded entities (see Smith 2005 for a discussion of this problem). In reality, the frontiers of the Kot Dijian and Harappan phases were probably not as well-defined as they appear to be on the maps, at least not in all areas. Some of the raw material sources that are located just beyond the northern and western-most known limits of those phases (such as the steatite deposits of Jammu or the vesuvianite-grossular source in Zhob) might have actually been internal to them. Even if they were not,

most of the external rock and mineral acquisition networks that residents of Harappa were involved in do not seem to have extended very far beyond the regions across which peoples of the society they belonged to were primarily settled.

The latter finding is significant as there is a great deal of evidence demonstrating that Harappan interaction networks extended as far as Mesopotamia, the Arabian Peninsula, Iran and Central Asia (see discussion and citations on p. 47). At present, however, none of the artifacts analyzed for this study can be firmly attributed to geologic sources in any of those regions. A few lead artifacts and an alabaster fragment from Harappa, as well as a handful of items from other sites (an alabaster vessel fragment from Mohenjo-daro, some silver ornaments from that city and Allahdino, the silver-lead ring from Gola Dhoro and a few objects I have seen in the collection of stone and metal artifacts from Dholavira), do not appear to be analogous to any analyzed occurrences of those materials in the Greater Indus region. The Pb isotope characteristics of six copper ore fragments from Harappa suggest that they may have from sources to the west of the Indus Valley or, perhaps, Oman. A few agate artifacts from Harappa, Nausharo and Chanhu-daro are chemically more analogous to agate used at the site of Shahr-i-Sokhta in eastern Iran than they are to samples collected from sources in Gujarat. The BMAC-like wig from Harappa does seem to be made from a type of steatite not typically used by Harappans. However, none of these data, although very intriguing, conclusively demonstrate that those materials were being acquired from sources in the Near East, Arabia, Iran or Central Asia. As far as the present study of stone and metal goods is concerned, imports from those regions remain as "invisible" (Crawford 1973) as ever.

This does not mean that such imports will always remain invisible. As I remarked above, some of the data are intriguing, in particular those for copper and silver artifacts. If Indus Civilization peoples were going to acquire rock and mineral goods from distant regions it would probably have been valuable metals such as those rather than materials like steatite or chert. The work I have done for this study on copper and silver has been extremely limited in terms of both the number of artifacts and the potential sources analyzed. As the datasets for those materials grow in size and expand in scope, imports from sources outside of the Greater Indus region may become much more evident.

The full extent of rock and mineral acquisition networks during the Transitional and Late Harappan (Cemetery H) phases (periods 4 and 5) at Harappa is difficult to judge based on the limited assemblage that is available for study. It is, nonetheless, evident that materials like steatite and vesuvianite-grossular were still being acquired from sources to well to the north of the site. Although these sources were external to the primary region across which Cemetery H peoples are presently known to have lived, this status could change. Ceramic evidence suggests that those Late Harappans might have dwelled as far north as the Swat Valley (Stacul 1985). No agate artifacts from this period were analyzed and so it not possible is to confirm if that material acquisition network to Gujarat was still in place. However, the lack of marine shell from Cemetery H levels suggests that interaction with peoples that far south had probably ceased by this time (Kenoyer 2005).

In summary to this section: stone and metal artifact provenience data indicates that, at one time or another, residents of Harappa interacted with peoples in most every major region in and around the Indus Valley. Strong connections with groups in areas to the north evidently existed during all phases at the site. Interaction/acquisition networks with Haryana, Balochistan, Sindh and Gujarat varied depending on the period (these changes are discussed in more detail in the next section). Limited and somewhat tenuous evidence exists for long-distance contacts between site residents and the ancient peoples of

the Rajasthan region. Although Indus Civilization interaction networks are know to have extended as far as Iran, Mesopotamia, eastern Arabia and Central Asia, these connections are not, as of yet, clearly evident in terms of the geologic proveniences of stone or metal artifacts at Harappa. Although external rock and mineral acquisition networks can be said to have always been a feature at Harappa, with the exception of during Period 1, most of those networks do not appear to have extended too far beyond the area across which peoples of the cultural phase its residents belonged to at the time were primarily settled.

We now turn to the second line of inquiry: *How did the patterns of inter-regional interaction/resource acquisition exhibited by residents of Harappa change over time?*

Ravi Phase residents of Harappa were involved in interaction/acquisition networks that extended north to the Badakhshan region of Afghanistan, south to the Arabian Sea coast, west to the frontier of Balochistan and east to the southern Haryana/northern Rajasthan region. Over the next two millennia, some of those networks intensified or were augmented. Others diminished in intensity or were abandoned entirely. Still others appear to have remained constant throughout Harappa's long prehistoric sequence. In many ways, the evident diachronic patterns of rock and mineral acquisition correspond well with the generally understood and accepted sequence of inter-regional interaction during the emergence, existence and decline of urban lifeways in the Greater Indus region. Some patterns, however, may require us to reassess the significance of certain regions and the peoples that dwelled in them to the urbanization process.

No major changes are, at present, evident in the overall pattern of rock and mineral acquisition at Harappa between the Ravi (Period 1) and Kot Diji (Period 2) phases. This is despite the fact that the geographic scope of the latter society was considerably more extensive than that of the former. The use of steatite from sources in regions to the north of the site may have intensified somewhat by Period 2. Also, the Kot Diji Phase is the first in which agate from Gujarat and alabaster from the Salt Range has been positively identified at the site. Such patterns should be treated cautiously, however, as the sample from Period 1 levels is extremely limited (only two steatite fragments and no agate or alabaster artifacts from earlier Ravi Phase contexts were analyzed).

The most significant changes in raw material source usage at Harappa took place around the Kot Diji to Harappa Phase transition (Period 2 to Period 3A). At that time, the acquisition of various cherts from occurrences to the north of the site (black Sakesar chert from the Salt Range and purple-hued chert-chalcedony most likely from the Pir Panjal Traps of Jammu and Kashmir) seems to have completely (or nearly so) ceased and given way to the use of tan-gray chert from the Rohri Hills of Sindh to the south. Similarly, grindingstone acquisition networks shifted in emphasis from relatively nearby sources to the north of Harappa (Kirana Hills) toward more distant ones to the west (Sulaiman Range). Steatite from a source in southern Balochistan also appears at this time (Period 3A) and is perhaps indicative of a new Harappan presence (at Bakkar Buthi) in that region.

Acquisition networks toward the south, west and east intensified as the urban phase progressed. By Period 3C, limestone from Sindh, Balochistan, Kutch and, perhaps, the Jaisalmer region of far western Rajasthan was being brought to Harappa. Lead from southern Balochistan as well as vesuvianite-grossular and alabaster from sources in northern Balochistan were likewise being acquired by that time. Agates and, very likely, the "Ernestite" used for making drills to perforate them were being brought from Gujarat. The Kirana Hills to the north had been practically abandoned as a grindingstone source. Although most stone used for that purpose still came from the Sulaiman Range, sources in distant Haryana (Kaliana Hills) to the east were steadily growing in importance.

It is thought that, by Period 5, residents of Harappa had ceased to interact with other Late Harappan peoples in the southern reaches of the Greater Indus region (Kenoyer 2005). However, it is not currently possible to support or refute this hypothesis with provenience data. No examples of the two materials that would most likely provide information on the matter – chert and agate, were analyzed from the site's limited Late Harappan levels. There is evidence from the grindingstone sub-assemblage that may be indicative of what is seen (Possehl 1997c) as an eastward demographic movement of Cemetery H Phase peoples during that period. The use of Pab sandstone from sources to the west appears to have fallen precipitously over Period 3C. Most grindingstone used during periods 4/5 was being brought from the Kaliana Hills, which are located around 400 km southeast of Harappa.

In contrast to the interaction/acquisition networks between Harappa and the southern, western and eastern parts of the Greater Indus region, which intensified and/or diminished over time, those extending toward the northern reaches of present-day Pakistan, India and Afghanistan appear to have remained fairly constant throughout the site's entire prehistoric sequence. Steatite, which has been analyzed for every period and shown to have mainly come from northern sources, and lapis lazuli, which is present in every phase, are the best indicators of this. Although chert from the Salt Range stopped being acquired after Period 2, alabaster from those mountains continued to be exploited during Period 3. Provenience data indicates that lead, vesuvianite and, perhaps, even small amounts of tan-gray chert were also acquired from northern sources during the urban phase at Harappa. Lapis lazuli, vesuvianite and steatite from the north demonstrate that interaction with the peoples of that region continued uninterrupted into the late/post-urban phase.

The diachronic perspective adopted for this line of inquiry permitted several ancillary issues related to changes in the use and/or acquisition of stone and metal goods at Harappa to be examined. When the composition of the site's rock and mineral assemblage was compared from period to period, it became evident that even though the geographic scope the Harappans' society changed significantly over time, the basic suite of raw materials they used remained, more or less, the same. While there are some variations between assemblages of different phases, most can be attributed to the lower probability of recovering less abundant varieties in less extensively excavated levels (recall Figure 4.12 and the discussion on p. 99). The likely exceptions are for vesuvianite-grossular, "Ernestite," and limestone. Each of these materials seems to have been primarily (or exclusively in the case of "Ernestite") acquired and used during the latter portion of the urban phase (ca. late Period 3B and Period 3C). The coincident appearance of the first two was quite probably related. Beadmakers at Harappa simply could not have perforated vesuvianite-grossular until "Ernestite" was discovered or its source otherwise became accessible. I consider the former to be more likely the case as the results of the agate provenience study (Chapter 8) indicate that raw materials from Gujarat – the region from which "Ernestite" most likely came, were accessible to site craftsmen from at least Period 2 onwards. Limestone, on the other hand, was abundant in almost every part of the Greater Indus region to which Harappans of any period had access. I have argued (pp. 616-617) that its use to create bulk-sized, non-utilitarian objects during the late urban phase probably represents a new development in the way that Harappans (not just at Harappa but also at Mohenjo-daro) expressed social power through the consumption and display of stone.

The diachronic perspective revealed that acquisition patterns for certain utilitarian stone goods at Harappa change significantly over time. It is clear that the Ravi Phase founders of the settlement already participated in extensive (described above) inter-regional interaction networks. The stones they

acquired through the more far reaching ones were ornamental materials like lapis lazuli and steatite. Utilitarian goods – namely grindingstone and chert, were primarily obtained from the closest occurrences, which contained material of marginal quality. This remained the case during the subsequent Kot Diji Phase, although use of higher quality materials from more distant regions did increase somewhat. With the onset of the fully urban phase (Period 3), the closest sources entirely (or nearly so) ceased to be exploited. This trend toward the acquisition of higher quality utilitarian stone from remote occurrences was probably due, in part, to the expanding geographic scope of the Harappans' society as well as the development/improvement of technologies (wheeled carts and watercraft) necessary to transport goods in bulk sizes and quantities over long distances. With regard to chert from the Rohri Hills of Sindh, which appears to have not only been the primary type used by residents of Harappa during the Integration Era but also by Indus Civilization peoples across northwestern South Asia, the trend is probably also indicative of an utilitarian material becoming a widely used symbol of group identity and a key item of exchange in the extra-regional economy. Ratnagar suggested (2001a: 354) that the distribution of Rohri chert was a "process handled by the rulers" of Indus society. While I agree (with qualifications – see p. 480), Smith has shown (1999) that long-distance trade networks for "ordinary domestic goods" had, at times, flourished in premodern South Asia without a "centralized government to provide economic infrastructure" (ibid.: 110).

In summary to this section: when the composition of Harappa's rock and mineral artifact assemblage and the geologic proveniences of select items analyzed/examined from it are regarded diachronically, we see that the inter-regional acquisition/interaction and material usage patterns of its residents in some ways changed and in other ways remained steady over the period of time that urban lifeways emerged in northwestern South Asia. During Period 1, acquisition networks already extended to the limits of the Greater Indus region even though the cultural phase that site residents then belonged to was confined to the western Punjab Plain. The strongest connections, which were with regions to the north of the settlement, seem to have continued uninterrupted (although not unchanged) from this time through Period 5 (Late Harappa Phase). As the different regional Early Harappan phases coalesced into the multi-regional the Indus Civilization, the Harappans' acquisition networks toward the south, west and east intensified and, in areas like Balochistan, expanded. The most significant changes in raw material source usage occurred around the Kot Diji to Harappa Phase transition (ca. Period 2 to Period 3A). At that time, the primary chert acquisition network shifted from the north to the south and grindingstone acquisition patterns expanded beyond the nearest occurrences toward much more distant sources of higher quality stone. The basic suit of raw material types used at the site remained more or less the same from the Early Harappa through the Harappa Phase, however. It was not until late in the urban phase (ca. Period 3C) that site residents began to acquire (at least on a large scale) varieties of stone like vesuvianite-grossular, "Ernestite" and limestone. During the post-urban Late Harappa Phase, inter-regional acquisition networks extending toward the east intensified while those to the south and west diminished or ceased.

The third line and final of inquiry asked: *Did synchronic variations in the patterns of rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?*

Synchronic assessments of Harappa's rock and mineral artifacts assemblage revealed mainly similarities but also a few notable differences between its mounded areas. Few significant variations in the geologic proveniences of stone and metal artifacts from different mounds were observed. During periods 3B and 3C, the residents of mounds E/ET

seem to have been the only Harappans utilizing alabaster from and "unknown" source, which I believe to likely be located somewhere in Jammu and Kashmir or the NWFP. Other than that, it would appear that, during all periods, Harappans living and working in different parts of the site had access to and were acquiring raw materials and/or finished goods derived from the same geologic sources. Slight variations in source proportions were sometimes evident between mound sub-assemblages, however. The inhabitants of mounds E and ET always seem to have used more Pab sandstone from the Sulaiman Range than their contemporaries dwelling on mounds AB and F. During Period 3C, the people of Mound F appear to have used at least twice as much Delhi quartzite from southern Haryana as those in other areas of Harappa. They also may have utilized steatite from northern Rajasthan more than other site residents during that same period. While this might indicate that Harappans dwelling in these parts of the site had stronger trade connections with the peoples of those distant regions, such patterns should be treated with caution. Many of the apparent variations could be due to recovery bias (see p. 99) as fewer trenches were excavated on mounds AB and F as compared to mounds E and ET.

The synchronic distribution patterns of rock and mineral artifacts at Harappa suggest that, during each period, people dwelling/working within the site's four main walled areas (mounds AB, F, E and ET) were using (and presumably had more or less equal access to) the same basic suite of raw materials. Most variations, where they are evident, are likely due to the low probability of recovering less abundant material varieties on all mounds. The only genuine exceptions are for "Ernestite" and vesuvianite-grossular (see the argument presented in Appendix 9.9), which seem to have been mainly used on mounds E and ET during periods 3B and 3C. Without "Ernestite" Harappans could not have perforated a stone as hard as vesuvianite-grossular. Kenoyer has suggested (1997b: 272) that its acquisition and use was a "closely guarded trade secret."

Other than the two varieties of stone just discussed, there is little synchronic variation of material use (or provenience) within the rock and mineral assemblage that might indicate different groups, whose "centers of power" (Kenoyer 1997a: 69) were Harappa's walled mounds, controlled access to specific material types. Of course, a raw material, such as steatite from the Hazara source, might have first been acquired by the residents of one mound and then distributed to consumers on the others. However, such an activity, if it occurred, cannot be detected using the methods employed in this study.

The few genuine synchronic variations within Harappa's rock and mineral assemblage are very informative, particularly with regard to the relationship between the adjoining mounds E and ET. In addition to being the primary locations where "Ernestite" and vesuvianite-grossular were used, the two mounds exhibit grindingstone acquisition patterns that are practically mirror-images of one another. The production/use of alabaster bangles to seems to have been exclusive to these two areas as well. These patterns of material use and production suggest that the inhabitants mounds E and ET were closely related and lend support the view (Kenoyer 1998: 55) that latter was an outgrowth or "suburb" that grew from and was incorporated into the former during Period 3B.

## DISCUSSION

Now that all of the provenience determinations have been brought to bear on the three lines of inquiry, some implications of what has been learned can be discussed.

## The development and nature of Harappan rock and mineral acquisition networks

As far back as the Neolithic Period at Mehrgarh (ca. 7000 BC), Indus Tradition peoples were obtaining ornaments made of materials from extremely remote sources. Eventually, peoples there and at other Early Harappan Period settlements in the Greater Indus region began acquiring those materials in raw form and transforming them into items would have served to enhance the wealth, status and power of those who owned and controlled them. From this, Raymond and Bridget Allchin observed (1982: 107), and others later concurred (Kenoyer 1998: 38; Possehl 1999: 680), that the "trade in luxury goods, often over long distances, had already been established for thousands of years before the beginning of Indus urbanism." The results of this study confirm that long-distance acquisition networks for prestige-related rock and mineral goods and resources were indeed already in existence at the time of Harappa's founding. Their establishment did not, for the most part, either immediately precede or accompany the incipient-urban (Kot Diji) or fully urban (Harappa) phases at that site. Instead there seems to have been a steady intensification and augmentation of existing inter-regional networks during the millennium or so leading up to emergence of the Indus Civilization at around 2600 BC. Long-distance trade, therefore, should not be regarded as a new (or even particularly uncommon) phenomenon that alone prompted the socio-political developments that led to urbanism in northwestern South Asia. Rather, long-distance trade networks were ancient and intrinsic features of Indus Tradition societies whose existence facilitated the urbanization of the region and which themselves underwent significant changes during that process.

One of the most significant changes was the trend toward the acquisition of two types of utilitarian stone – chert and grindingstone, through long-distance trade networks. Generally in pre-modern societies, goods of this nature tended to circulate in exchange networks that were much more localized as compared to those for prestige-related resources and products (Hirth 1992). Of course, at Harappa and at most other Harappan settlements located on plains of the Indus Valley proper, utilitarian stone acquisition networks were necessarily broad to begin with. In her model of the scales of trade in Early Historic Period India, Monica Smith defined (2002: 140) *local trade* as an activity that could be undertaken in a single day by the fastest means of conveyance available. In this regard, there were no local trade networks for any kind of stone or metal at Harappa simply because there were no local sources. There was only *regional trade* (that taking place within the territory of a single cultural unit of a size that required those transporting something to spend a period of time away from their place of residence) and *long-distance trade* (which takes place across expanses that encompass multiple cultural phases and/or and ecological zones) (ibid.). The extent of grindingstone and chert acquisition networks, even though broad to begin with, expanded significantly – from regional to long-distance, as urban lifeways emerged at Harappa and in the Greater Indus region. I have argued that this was due, in part, to the development/improvement of the wheeled carts and watercraft needed to transport goods in bulk sizes and quantities. However, another important contributing factor would have been the expansion over time of the system of internal trade networks through which residents of Harappa acquired stone.

Rock and mineral artifacts deriving from external sources – i.e., those located outside of the geographic area encompassed by settlements of the cultural phase to which residents of Harappa belonged, have been recovered from every chronological period and sub-period at the site. It can be stated, therefore, that external trade was continuous feature of Indus society, at least at Harappa itself. It was most pronounced during Period 1 when, as far as we presently know, Ravi Phase peoples were settled only in the western Punjab. However, from that time through the

Harappa Phase, the system of internal acquisition networks to which Harappa's residents had access steadily expanded as the geographic scope of the society that they were a part of became larger and sources previously accessible only through external networks were encompassed into it. During Period 2, that system stretched from the Potwar Plateau to Sindh Kohistan. By Period 3, site residents could have acquired rocks and minerals from Haryana and large parts of Balochistan and Gujarat through internal trade networks. Although there would have been instances where entirely new internal networks were established as Early Harappan and/or Harappan peoples moved into new areas, the development process is best characterized as expansion through integration. That is, the vast internal system of the Indus Civilization was largely built upon various existing regional systems that were joined during the Integration Era.

Significantly, all but a few of the identified and probable rock and mineral sources that appear to have been external to the Indus system during the Integration Era are located in regions that were immediately adjacent to it. Moreover, the situation along those "peripheries" is often far from clear. Many of the sources lying just beyond the area where Harappan sites are found might well have been within the Indus system (recall the discussion on p. 235). Whatever the case actually was, the results of this study indicate that, as far as rocks and minerals are concerned, the vast majority of external trade that residents of Harappa were engaged in involved interaction with peoples along the highland margins of the Greater Indus region. It is, of course, well-documented that Indus Civilization peoples had contacts with and sometimes even dwelled in regions far beyond this (see p. 47). However, like Shaffer (1982: 200) and Chakrabarti (1990: 169), I found little evidence to support the views of researchers (Asthana 1978; Possehl 1990; Ratnagar 2004) who feel that long-distance trade with the ancient peoples of western Asia, in particular Mesopotamia, "may have played a significant role in … the development of Indus urbanization" (Possehl 1990: 276-277). It is true that the artifacts analyzed for this study were not compared to any sources in western Asia and that there were a small number that could not be firmly attributed occurrences in the Greater Indus region. Nevertheless, at this point I have to concur with Lahiri's assessment (1990: 441) that while at times "there may have been raw materials involved in the long-distance trade between the Indus Valley, the Persian Gulf, Iran and Mesopotamia there is no reason to argue that Harappa or any other site of the Indus Civilization were in any way solely or even significantly dependent on such raw materials." Harappans would have found multiple occurrences of practically every rock and mineral resource they required in abundance within or directly adjacent to the Greater Indus region.

Although I interpret the evidence presented in this book as providing little support for the supposition that long-distance trade with western Asia significantly influenced the development of urban lifeways in the Greater Indus region, this does not diminish the fact that such trade indeed took place or the possibility that it may have been vitally important to *some* groups within Harappan society. That no firm evidence for those trade relationships was detected in this study of Harappa's rock and mineral artifact assemblage probably has a lot to do with the types of materials examined (see p. 477) as well as the geographic location of the site itself (this latter point is discussed in more detail below). However, when such evidence is detected at Harappa or at another Indus Civilization site (as I am confident it eventually will be) it must be put into perspective.

Kenoyer is probably correct in his assertion (1991a: 361) that "external trade was a critical factor to the internal controls that maintained the Indus structure." Controlling access to and managing the distribution of goods or raw materials from outside

of the Greater Indus region would have been an important strategy for some elite groups in Harappan society who were competing (for wealth, power and prestige) with other groups that controlled different sources or kinds of essential resources. We may be certain that those Harappans whose relationships in Arabia, Iran or Mesopotamia enabled them to import goods or raw materials from those distant regions into the Indus system benefited greatly by doing so. It is possible that there where some groups (families, guilds, merchant castes, etc.) whose livelihoods were based largely or even entirely upon their network ties with regions external to the Harappan homeland. However, those networks were only one aspect of what we are now beginning to realize was a vast, multi-regional and multi-tiered acquisition system that was primarily centered on raw materials that were usually available in multiple locations across northwestern South Asia. Ultimately, as Shaffer once remarked (1982: 191), "the evidence indicates that Harappan external trade with the West cannot be compared to that which existed between contemporary Mesopotamia and the Iranian Plateau or Persian Gulf, in terms of intensity, regularity or relative importance to cultural developments in these regions."

### Competition and the control of essential resources

The extensive inter-regional trade system discussed above, in combination with the wide distribution and multiple occurrences of essential resources across northwestern South Asia, is argued (Kenoyer 2000: 89-90) to have been a critical stimulus for economic competition and socio-political development in the ancient Indus Valley. That is, this unique setting is seen as having presented early village communities and, eventually, different groups of city-dwellers with wide-ranging opportunities to vie with one another for wealth, power and social-standing by controlling raw material sources and/or access to material acquisition networks. It was, in essence, an optimal cultural and geographic environment for the promotion and maintenance of the social and political stratification characteristic of an urbanized society like the Indus Civilization.

In this book, I have attempted to shed light on competition and the control of essential goods and resources at Harappa by conducting phase-by-phase synchronic assessments of the material variety and provenience composition the site's rock and mineral artifact assemblage. Although some striking differences that can be construed as evidence for these behaviors were detected between different mounds, on the whole, the results were equivocal. Part of the trouble no doubt had to do with the sample. For all chronological phases, only a small, non-representative fraction of the site's mounds has been excavated. The methodology used is clearly better suited to a site where multiple large-scale horizontal excavations have taken place. Perhaps the biggest problem was the likelihood that even though many rock and mineral varieties might have been initially acquired by Harappans dwelling on one mound, they were subsequently dispersed to residents in other parts of the site, thus muting the inter-mound patterns of material control that I had hoped to detect.

The results of the site-wise synchronic assessments of material usage and provenience at Harappa have already been summarized above. In my estimation, the only usage patterns that are likely to be genuinely indicative of control of resources and competition between groups at the site are those for vesuvianite-grossular garnet and "Ernestite" – both of which are found mainly (≈ 90% of all artifacts in each variety) on mounds E and ET during periods 3B and 3C. I have examined these patterns at length (pp. 318-324 and Appendix 9.9) and explained how "Ernestite" was the only drilling material that Harappans possessed that could have been used to perforate a stone as hard as vesuvianite-grossular. I would argue that the distribution at the site of artifacts composed of

these two materials is directly related to "Ernestite" being, as Kenoyer has suggested (1997b: 272), a "closely guarded [*controlled*] trade secret." Only those craftspeople on mounds E and ET who were working with drills made from this stone could have fashioned vibrant green vesuvianite-grossular beads. This would have translated into a *competitive* advantage for elites in that part of the site who controlled the production of status-defining items. The distinctive Harappan-style long-barrel carnelian bead is also an item that only those who controlled access to "Ernestite" drills could have had manufactured. I have not undertaken a study of the locations at Harappa where such beads were made but if production was found to have been centered on mounds E and ET then that would provide excellent supporting evidence for the pattern of material control that I have argued existed.

The remaining material distribution patterns indicate that, by and large, people living in all parts of Harappa were using the same kinds of rocks and minerals. Similarly, when the provenience patterns for individual material types were examined synchronically, it became clear that, barring a few variations in source proportions that are of arguable meaning (see p. 235), all site residents had access to and were using materials derived from the same geologic occurrences. These patterns in no way rule out the possibility that there were certain groups at Harappa who had network ties that enabled them to alone control the importation of rocks and minerals from specific regions or sources. The problem (for me in terms of this study) is that restricting all imported materials to their own parts of the site would not, in most cases ("Ernestite" excepted), have been of much benefit to such groups. They could have garnered far more economic, social and politic power in the course of transferring (bartering, selling, gifting, providing as tribute or tax) their surplus resources to Harappans living in other areas of the site. Detecting group control of specific materials and material sources in the archaeological record of the site is, for this reason, problematic.

Even though intra-site exchanges have obscured inter-mound patterns, it is still possible to infer something about competition and the control of rock and mineral resources at Harappa by looking at the overall provenience results. Kenoyer argued (1995b: 221-222) that the existence of multiple potential sources for most raw material varieties used by Indus Civilization peoples "must have presented a unique opportunity for competition between merchants and suppliers and a major problem for elites trying to control access to potentially high status materials." For each of the eight rock and mineral varieties from Harappa that were examined in detail, I was able to confirm that, during most periods, site residents utilized raw material from geologic occurrences located in two or more different regions. This likely indicates that multiple groups were involved in the supply of these material varieties. That is say, it seems unlikely that, for example, a group involved in transporting a material like Pab sandstone from sources over 200 km west of Harappa in the Sulaiman Range would be the very same group that supplied Delhi quartzite to the site from a source nearly 400 km to the east. Although the exact nature of any competition between various suppliers is difficult to speculate about at this time, it is now quite evident that consumers at Harappa would have had multiple choices for many or most of the raw materials that they wished to acquire. This situation would indeed have proved problematic for elites trying to control access to certain types of prestige-related rocks and minerals.

Finally, I interpret the dramatic shift in chert source utilization that occurs at the beginning of Period 3A as likely being the result of a group of Harappans monopolizing the market for that utilitarian stone. Recall (p. 144) that Ravi and Kot Diji Phase residents of Harappa were acquiring this material variety from no less than three different sources. By the Harappa Phase, however, chert from

the Rohri Hills of Sindh was almost[2)] exclusively used there and, apparently, at other Harappan settlements throughout the Greater Indus region. There were probably a variety of reasons why, even though many alternate sources would have been accessible to Indus Civilization peoples, this particular material type was utilized so extensively. To begin with, it was simply the best quality chert available. The large nodules of homogenous material occurring in the Rohri Hills permitted standardized long blades to be produced on an "extraordinary scale" (Biagi and Cremaschi 1991: 97). There were possibly aesthetic and/or symbolic reasons as well. The black-brown and colorful variegated cherts and jaspers that were popular materials for making stone tools in the Early Harappan Period might have fallen out favor. Something about the light-tan/gray homogenous and concentric banded types of Rohri Hills chert may have appealed to the Harappans' sense of purity and order. The highly distinct appearance and consistent density of the banded type are probably the main reasons why it was the most commonly used raw material for making Harappan-style standardized cubical weights. Weights with this appearance could not be replicated (i.e. faked) in any other type of stone.

Ratnagar has argued (2001a: 354) that the pan-regional distribution of Rohri Hills chert type reflects a "process handled by the rulers" of Indus society. Although I agree, I am not inclined to conceptualize those rulers as having been leaders of a single, politically unified extra-regional state (Ratnagar 1991: 169). Given the size and restricted geographic setting of the Rohri Hills within the Indus Valley, they could conceivably have been controlled by one community of Harappans based in northern Sindh that oversaw the extraction and monopolized the distribution of the valuable utilitarian resource there. I see that community as having been one of the many elite factions (merchants, landowners, ritual specialists, etc.) who, it is argued (Kenoyer 1994a: 77), were competing with one another for political dominance in Indus cities. If one judges by the apparent ubiquity of this particular material type at settlements large and small across the Greater Indus region, then it is reasonable to conclude that these Harappan "chert barons" (who may have also had interests in other industries and areas) were exceptionally successful in that regard. Underlying their success were the factors that made their product widely desirable (discussed in the preceding paragraph), the technologies (wheeled carts and watercraft) that enabled them to transport it in large quantities over long distances and, importantly, the location of the Rohri Hills themselves in the geographic center of the Indus Basin along or near what would have been the principal north-south Harappan interaction/trade network.

### Harappan inter-cultural relationships

One of the stated aims (p. 11) of this study was to identify and evaluate the significance of Harappan inter-cultural relationships by studying the trade of essential raw materials. The peoples that residents of Harappa were interacting with, either directly or indirectly, when acquiring rock and mineral resources have now been identified (the results were summarized on pp. 474-476). During the Regionalization Era, some of those peoples were members of same cultural phase to which site residents belonged and some were part of different Early Harappan phases that would eventually come to be incorporated into the Indus Civilization during the Integration Era. There were others, however, which belonged to non-Early Harappan cultural phases. Later, during the Integration Era, site residents were interacting with fellow Harappans as well as various non-Indus Civilization peoples in highland areas

2) There are indications that cherts from sources in regions other than the Rohri Hills were utilized to a very limited extent at Harappa (Chapter 5) and Mohenjo-Daro (Kenoyer 1984a: 119) during the Harappan Period.

adjacent to the Greater Indus region. In this section, I discuss the significance of these non-Early Harappan and non-Indus inter-cultural relationships.

Judging by rock and mineral acquisition patterns, the most important and enduring inter-cultural relationships for residents of Harappa were those with groups dwelling in regions north of the upper Indus Basin. Specifically, these would have been with Northern Neolithic Phase peoples – the highland agro-pastoralists found across the Swat, northern Potwar and Kashmir regions from the Early Harappan through the Harappan periods – and peoples of the "Late" Kot Diji Phase in the Potwar, Bannu and Gomal regions during the Harappan Period. With regard to the latter phase, Raymond Allchin advanced (1984: 53) three theories as to why it persisted in the north while Kot Dijian peoples in the south, including those at Harappa, were integrated into the Indus Civilization. The first was environmental. The intensive agriculture that Harappans practiced in the Indus Valley proper, Allchin argued, may not have been suited to the climate or irrigation regime of the north. Although this is not my area of expertise, it is my feeling that these were probably not inhibiting factors as agriculturalists had thrived in the Bannu and Gomal regions from the Sheri Khan Tarakai Phase (ca. 5th and 4th millennia BC) onwards. If Early Harappans could sustain settlements in the north then it is likely that Harappans could have also. Allchin's second theory was economic. The north, he hypothesized, may not have "offered raw materials which were in demand in the Indus heartland" (ibid.). This was plainly not the case as I have demonstrated repeatedly throughout this book. In fact, we now know the opposite to have been true. The third theory was political. Allchin speculated that there may have been an "active opposition" by "Late" Kot Dijians in the north to Harappan control over the region (ibid.). This is conceivable, although it should be noted that there is no evidence whatsoever for violent confrontations between those two societies.

Although rock and mineral artifact provenience data demonstrate that residents of Harappa interacted with peoples to the north of the site that belonged to cultural phases other than their own, they provide little information as to the nature of those relationships. It may be helpful, therefore, to briefly consider the results in terms of the same three or four basic interaction scenarios that were discussed earlier (p. 235) in regard to steatite acquisition networks.

One possible scenario is that Early Harappans (Ravi Phase peoples and Kot Dijians) and Harappans never directly encountered peoples of the northern highland regions where many of the identified rock and mineral sources are located. Instead, members of another cultural phase(s) acted as an intermediary between them. This scenario is unlikely to have been true during the Early Harappan Period. Firstly, there is no indication that any other cultural phases were then present in the north who might have acted as intermediaries. Secondly, Kot Dijian settlements are found up to the northern edge of the Potwar Plateau. Thus, during Period 2 at Harappa, site residents could conceivably have acquired raw materials from fellow (at that time) Kot Dijians who dwelled in the north and made forays directly (without intermediaries) into adjacent (for them) source areas occupied by Northern Neolithic peoples. During Period 3 at Harappa, however, the "Late" Kot Dijian peoples living along the northern periphery of the Greater Indus region may themselves have sometimes served as intermediaries between Northern Neolithic peoples and Harappans to the south. In fact, some of the Kot Dijian materials reported at Northern Neolithic sites might actually be from this time period. For example, among the local Neolithic materials at Ghalegay rock shelter in Swat, Stacul described (1987: 39-40) ceramics comparable to those at "sites displaying the late Kot Dijian style" in levels that produced a calibrated radiocarbon date of 2180 BC (ca. early Period 3C at Harappa).

Another possibility is that Northern Neolithic

and/or "Late" Kot Dijian peoples sometimes traveled southward to Harappan settlements on the Punjab Plain, carrying with them raw materials for trade that they obtained from sources in their home territories. This scenario is most applicable to peoples of the former cultural phase who, by the mid-to-late third millennium BC, were reportedly raising domesticated sheep, goat and cattle at highland settlements like Gufkral in the Kashmir Valley (Sharma 1983a, 1983b). The seasonal migration regimes of herders and their flocks are the foundation of the ancient and still continuing "symbiotic relationships" between highland and lowland peoples all along "western borderlands" of the Indus Valley (Fairservis 1975: 233; Possehl 1999: 14-15). Shaffer argued (1978: 153) that because their wide-ranging transhumant lifeways afforded them "knowledge of points of consumption, as well as possible sources of supply," those pastoralists would have been the primary procurers and conveyers of raw materials from prehistoric Balochistan. Northern Neolithic herders, like historical Himalayan pastoralists such as the Gaddis and Gujars (Drew 1875: 107-111), might have performed a similar role in the "northern borderlands" of the Greater Indus region. The vast stretches of grazing land that were available in the bar uplands of the western Punjab doabs (Possehl 1984) would certainly have been an impetus for them to migrate southward to that region during the winter months. The Northern Neolithic sites that Possehl reported (1999: 548) in the Thal Desert tract (the Indus-Jhelum doab) near Leiah might even be the remains of their seasonal camps. Still, no such sites have been identified anyway in the vicinity of Harappa and no artifacts (ceramics, stone tools, etc.) that would provide an unambiguous association with that cultural phase have even been recovered there.

A seemingly more likely scenario would be one involving Northern Neolithic and "Late" Kot Dijian peoples coming into contact with Harappans in the highland-lowland transition zone where those cultural phases met. Evidence for inter-cultural interaction between these phases at Early Harappan and Harappan settlements excavated along that zone is limited[3], however. That is to say, material culture belonging to non-Harappan phases is not as evident at them as it is at, for example, sites along the southern Indus frontier in Gujarat like Nagwada (Hegde *et al*. 1988) and Gola Dhoro (Bhan *et al*. 2004). Certainly nothing resembling an enclave of Northern Neolithic or "Late" Kot Diji Phase peoples dwelling at a Harappan settlement (or vice-versa) has ever been discovered along the northern highland-lowland transition zone. In some places, peoples of different phases do seem to have dwelled in close proximity to one another. For example, on the Gomal Plain, the small Harappan site of Hisham Dehri (Dani 1971: 31) is located just 500 meters north-northeast of the larger Kot Dijian site of Rehman Dehri. Two radiocarbon samples taken from sealed floor levels in latter site's third and final occupational phase (RHD III) provided calibrated dates of 2170 BC and 2090 BC (Thomas and Allchin 1971: 39-40), which indicates that it was occupied well into the Harappan Period. It is, therefore, highly likely that the "Late" Kot Dijians of Rehman Dehri and the Harappans of Hisham Dehri were contemporaries living within sight of one another[4]. Currently, we can only speculate about the nature of the relationship between the peoples of those settlements. However, there is little evidence to suggest that it was hostile[5]. Whatever the situation actually was, it is clear that

3) A single burial at Ropar and some ceramics at Chandigarh (Ropar and Chandigarh are Harappan sites located in the extreme eastern part of the highland-lowland transition zone under discussion – see Figure 2.5) exhibit Northern Neolithic parallels (Possehl 1999: 552). A few Northern Neolithic ceramic forms continue in very limited numbers into mid-Kot Diji Phase levels (Period II) at Sarai Khola (Mughal 1972: 37).

4) The same situation may have existed to the southwest at the sites of Maru I and Maru II (Khan *et al*. 2000).

while "Late" Kot Dijians on the Gomal Plain and elsewhere somehow resisted social integration with Indus Civilization peoples, this did not impede Harappan acquisition of raw materials from beyond the northern frontier of the Greater Indus region.

Harappans themselves may have sometimes traveled beyond the northern frontier and interacted directly with peoples dwelling in rock and mineral source areas. Of all the basic scenarios reviewed here, this is the one we can be most confident actually occurred. The reason is because of the existence of the Indus Civilization site of Shortughaï. Harappans obviously had to have made the journey to northern Afghanistan at least once in order to found that settlement. It is probably be safe to assume that they traveled there and returned multiple times. Figure 13.9 is a map depicting the major routes leading from the upper Indus Basin to Shortughaï. It is recognized that there are numerous other pathways that Harappans might have taken[6] and that just because a particular one (such as the Khyber Pass) is famous in the modern era does necessarily mean that it was important in the past. However, those depicted here became the best known and most utilized historically mainly because they were among the most expedient. Even owing for changing landforms in this tectonically active region, it is highly likely that they would have been during the prehistoric period as well. In addition to the possible routes, identified and probable Harappan Period rock and mineral sources are plotted on the map along with pertinent Indus Civilization, "Late" Kot Dijian and Northern Neolithic sites.

In Appendix 13.1, I evaluate the different routes depicted on Figure 13.9 in detail. Although Indus Civilization peoples may have journeyed to Shortughaï along any of them, I have concluded that the evidence most favors a route that first passed through either the Potwar Plateau / Peshawar Valley regions or the Gomal Plain. That no Harappan sites (or non-Harappan sites with evidence Harappan contacts) have yet been discovered in the former regions does not greatly diminish this assertion as there are large parts of northern Pakistan that remain to be systematically surveyed. Three decades ago, Possehl remarked (1979: 545-546) upon the apparent paucity of Indus Civilization settlements in the western Punjab. Since then, surveys in that region (some of which remain incomplete) have revealed the existence of a number of such sites (recall the discussion on pp. 39-40). Alternately, over two decades of intensive work by the Bannu Archaeological Project (Khan *et al*. 2002b) has failed to detect any Harappan presence in that region, which is one of the reasons why I consider it unlikely to have been an important pathway to Shortughaï. The results of this study suggests that there may be Harappan sites yet to be discovered across the Potwar Plateau and in the Peshawar Valley; probably in the large unsurveyed areas and/or beneath the numerous Historic Period settlements that exist in both regions.

Harappans journeying to Shortughaï by a route passing through the Potwar Plateau and Peshawar Valley would have encountered "Late" Kot Dijians and, probably (certainly if they were continuing north via the Swat Valley), Northern Neolithic Phase peoples too. Who they might have interacted with in regions beyond this is unclear. The cultural landscape of late

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5) Bridget Allchin's theory (1982: 237) that Hisham Dehri was the camp of a "Harappan army" laying siege to Rehman Dehri does not hold up well under scrutiny – i.e., terracotta "cakes," which are found in abundance at Hisham Dheri, were probably not weapons (projectiles) and there is no other evidence for violent conflict. Xu's interpretation (1990) that Kot Dijians and Harappans had an "antagonistic" relationship is based largely on the existence of a "burnt" layer at the site of Kot Diji that may not have actually been the result of conflict.

6) For instance, in addition to the primary Kurram and the Tochi river routes, there are 32 minor passes from the Bannu Basin through the Waziristan Hills alone (Thomas and Knox 1994: 93).

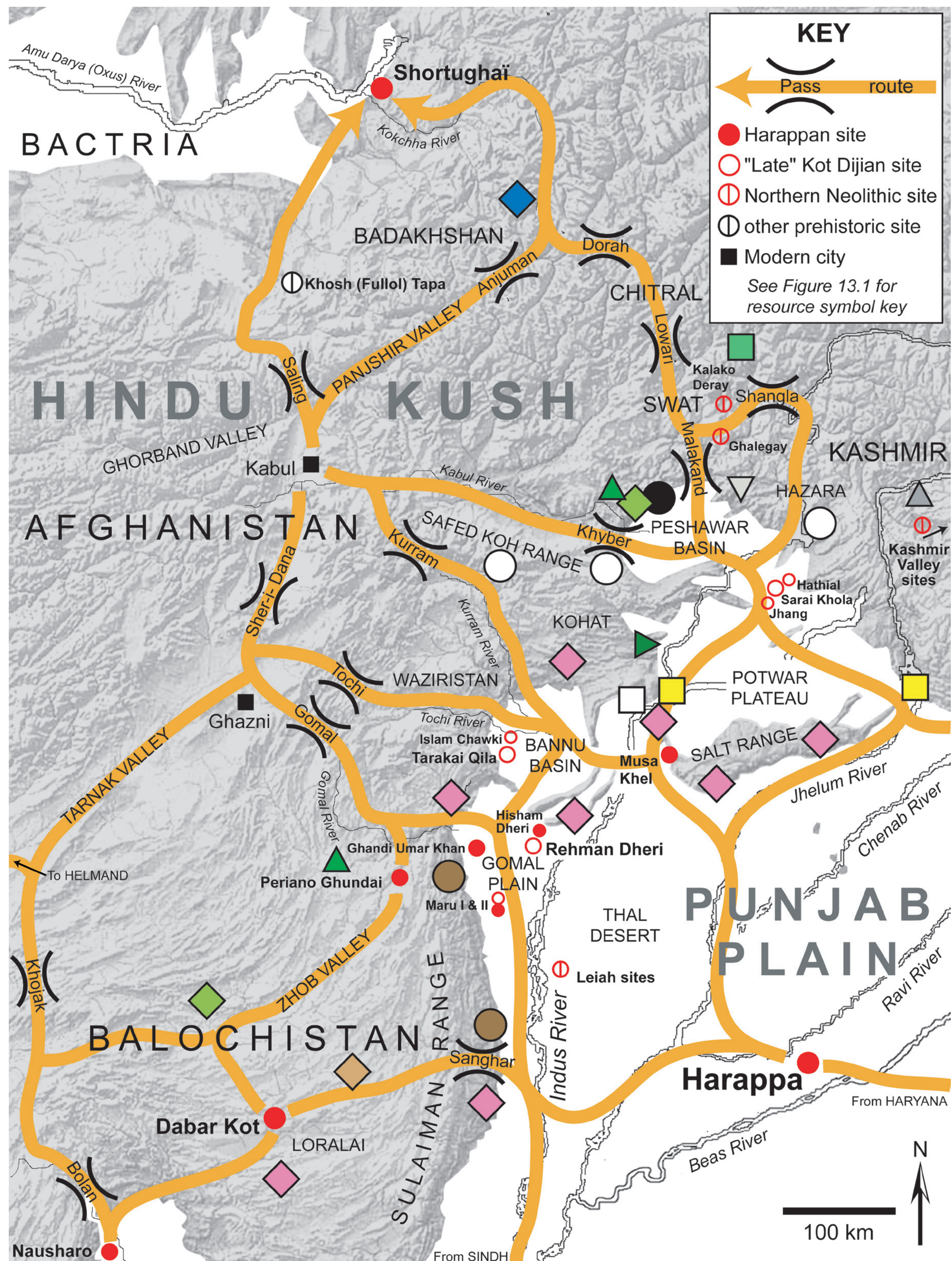



**Figure 13.9** Major routes from the upper Indus Basin to the Harappan site of Shortughaï.

prehistoric northeastern Afghanistan is still largely *terra incognita*. What little evidence exists indicates that it was a region where peoples from distant lands dwelled alongside indigenous Chalcolithic phases (Lyonnet 1977, 1981). The fragmentary gold and silver vessels that were recovered from a hoard at Khosh (Fullol) Tapa and dated to ca. 2600-1700 BC had stylistic parallels linking them to both the Helmand region and Mesopotamia (Maxwell-Hyslop 1982; Tosi and Warwick 1972). Valuable resources, especially

lapis lazuli but also precious metals, were no doubt what impelled peoples from those distant lands to make the arduous journey to northern Afghanistan. Future research may eventually show that this region, like eastern Arabia, was one of the places where Harappans closely intermingled with multiple cultures from across Middle Asia.

Although it is difficult, at present, to say much about the nature and dynamics of Harappan relationships with non-Indus Civilization peoples in the north, they were clearly integral to the development and maintenance of urban lifeways at Harappa and, by extension, in the Greater Indus region. That having been said, these were not the only inter-cultural relationships detected in this study of Harappa's rock and mineral assemblage. There are indications (reviewed on p. 474) that site residents also interacted with non-Indus Civilization peoples dwelling in northern Rajasthan, southern Balochistan and southern Gujarat when acquiring certain varieties of stone and metal. That evidence, however, is far less abundant and far less varied than it is for the north. In some instances it is rather tenuous as well. Still, it would be a mistake to interpret it as suggesting that inter-cultural relationships with the non-Indus Civilization peoples of those regions were not also integral to the overall urbanization process in ancient northwestern South Asia. They may have been less important to the residents of Harappa than others, but Harappa was only one settlement (albeit a major one) in the vast Indus realm. Its residents were well-situated geographically to have and benefit from relations with peoples in the north. It stands to reason that the inter-cultural relationships of Harappans dwelling in Indus Civilization cities located in other regions may have been very different indeed.

## The primary rock and mineral resource catchment areas of Indus cities

One of the main accomplishments of this study has been to provide a new and detailed picture of the extent and direction of Harappa's rock and mineral catchment area. In this final discussion section, I use that understanding to model the catchment areas and acquisition/exchange patterns that might be associated with the other major Indus cities. I then briefly consider some of the undetected acquisition networks at Harappa from multi-regional perspective the model offers. I begin by reviewing Harappa's catchment area.

### *Harappa's primary rock and mineral catchment area*

In Chapter 4, I discussed how, in simple terms of distance to the nearest potential sources of the rocks and minerals recovered at the site, Harappa is oriented toward the highlands west and north of the upper Indus Basin (recall p. 101 and Figure 4.13). Of course, this is not particularly surprising if one just studies a good map. Geographically, Harappa is the Indus Civilization city located nearest to the Subcontinent's northwestern highlands and, thus, it was to be expected that many resources used at the site may come from that region. In fact, scholars like Fentress (1976), Ratnagar (1982) and Lahiri (1990) predicted this. In chapters five through twelve, I was able to confirm that a large portion of the stone and metal artifacts analyzed indeed were derived from sources within a broad, semi-circular zone that began directly west of Harappa in the Sulaiman Range and extended through to the highlands north-northeast of the site in Jammu. There were some significant exceptions – such as chert from the Rohri Hills of Sindh and agate from Gujarat. Harappa's full rock and mineral catchment area was extra-regional and extended from at least northern Afghanistan to Gujarat, perhaps much farther. Even so, I would argue that it is appropriate to characterize it as being *primarily* oriented toward the northwestern highland zone described above. I have highlighted this zone (primary catchment area) on Figure 13.10 using orange-shaded terrain. Broad arrows represent the general movement of raw materials

from the highlands toward Harappa (and not any one acquisition network).

Because of Harappa's location in the upper Indus Basin and its resident's now demonstrated acquisition/interaction links with the highland zone discussed above, I am not averse to informally labeling the site as the Indus Civilization's "gateway to the north." However, I expressly do not think it appropriate to characterize it using the formal geographic concept of "gateway settlement" (Burghardt 1971) as Ratnagar attempted to do in her article *The Location of Harappa* (1982). She hypothesized that the site was a lower-level tributary city on the Indus periphery that functioned as a "gateway" through which commodities from external sources flowed toward a primate city in the core, specifically, Mohenjo-daro. Because of this, it was thought that "transportation functions and facilities would outweigh the importance of manufacturing" at Harappa (Ratnagar 1982: 163). Ratnagar's hypothesis does not hold up under scrutiny but, to be fair, our understanding of settlement patterns in the Punjab, manufacturing activities at Harappa and the movement of goods and resources in the Greater Indus region has grown considerably since her article was published over a quarter-century ago. It is now understood that Harappa was not an isolated settlement on the northern Indus periphery (recall pp. 37-40) and that a huge and highly varied amount of craft manufacture took place there (Kenoyer and Miller 2007). Most importantly, we now know that, although the site's rock and mineral resource catchment area was largely oriented toward the northwestern highland zone, its residents had access to and were importing raw materials from all parts the Indus realm and, in some instances, beyond. Thus, Harappa was not merely a settlement through which commodities flowed from the hinterlands to the Indus core. It was a regional center of craft industries and trade as well as a nexus of inter-regional trade routes (Kenoyer 1995, Lahiri 1990).

Although Harappa was not a gateway city, there are indications that its residents were exporting some of the rocks and minerals they acquired from northern sources to consumers in other parts of the Indus realm. Most of the steatite artifacts analyzed to date from Mohenjo-daro, Rakhigarhi and Dholavira appear to be from the same northern occurrences (in the Hazara District, NWFP and the Kurram Agency, FATA) as the majority of those analyzed from Harappa. Likewise, most the vesuvianite-grossular fragments analyzed from Mohenjo-daro appear to be from the Sakhakot-Qila ophiolite on the northwest edge of the Peshawar Valley, just as were most from Harappa. While such provenience patterns obviously do not prove that these or any other raw materials from the northwest highland zone were transported along a particular route, given the primacy of Harappa in the upper Indus Basin and the orientation of its rock and mineral resource catchment area, it is not unreasonable to assume that they first came to that site before being traded elsewhere. Raw steatite may have been an especially valuable trade good for certain residents of Harappa. Recall (Chapter 7) that even though occurrences of that stone are found in most every region surrounding the Indus Valley, those that would have yielded raw material with one of the main properties that Indus consumers desired – i.e., to become white when heat-treated, are mostly located in the dolomitic sequences of the northern Subcontinent. To represent this possibly important trade good from Harappa and its the northwest rock and mineral catchment zone, I have added the word "steatite" below the placemark for the site on Figure 13.10 and have drawn orange arrows extending from it toward Haryana, Sindh and Gujarat.

***Projected primary catchment areas for other Indus Civilization cities***

I suggest here that most of the other major Indus Civilization cities probably had rock and mineral catchment areas similar to Harappa's in that they were

oriented toward adjacent highland regions and that certain high-value and/or unique material varieties found within each zone were traded to consumers throughout the Greater Indus region. Other researchers have made similar proposals (Asthana 1993; Fentress 1976; Lahiri 1992; Possehl 1993). However, the multi-regional model of acquisition and exchange that I offer here differs from past ones in several important ways: 1) Harappa's primary catchment area is now fairly well understood and is used to inform what those areas for the other Indus cities may have been like[7)], 2) a limited number of geologic provenience determinations for artifacts from other sites have been produced (recall Figure 13.8) that provide a glimpse into acquisition patterns in other parts of the Greater Indus region and 3) I have approached the modeling of the primary catchment areas with an up-to-date perspective on the geology of northwestern South Asia that earlier researchers lacked (see pp. 50-51).

One of the most striking features of the Indus Civilization is the roughly equidistant distribution of its five largest cities – Mohenjo-daro, Harappa, Rakhigarhi, Dholavira and Ganweriwala, across the Greater Indus region (Mughal 1994a: 56). While many factors no doubt promoted the growth of those urban centers in the specific locations where they are found, in terms of providing Harappans access to stone and metal resources within and surrounding the Indus Basin, they could not have been more optimally situated, either individually or collectively. I have projected primary rock and mineral catchment areas for Dholavira, Mohenjo-daro and Rakhigarhi on Figure 13.11 using red, blue and green (respectively) highlighted terrain. The omission of an area for Ganweriwala is explained below. As each provisional zone is introduced (starting with Dholavira and then moving northward), I make predictions regarding its extent and the major rock and mineral trade goods[8)] that we might expect to see associated with it.

Dholavira's primary rock and mineral resource catchment area likely encompassed all of present-day Gujarat as well as adjacent highland areas in southern Rajasthan and eastern Madhya Pradesh. Ornamental microcrystalline silicates obtained were almost without a doubt the primary exports from the city and this zone. I have represented these on Figure 13.11 using red arrows extending northward and the general term "agate," which I have confirmed (Chapter 8) was traded from sources in Gujarat to multiple Harappan sites in the Indus Valley proper. Other similar trade goods from this zone included yellow-brown banded limestone and, quite probably, "Ernestite" and amazonite.

The primary rock and mineral resource catchment area for Mohenjo-daro would have probably encompassed the highland areas of Sindh and as well as large parts of southern and west-central Balochistan. Based on its distribution at Harappan sites across the Greater Indus region, it is no doubt safe to assume that chert from the Rohri Hills was one of the primary trade goods from this zone. I have represented this on Figure 13.11 using blue arrows extending outward toward the upper and lower Indus Basin regions. Metal resources – lead metal, raw lead ores and, possibly, silver from southern Balochistan and copper from the Chagai area, were also likely important trade goods.

7) For rock and mineral resources at least, it is now possible to move beyond projecting hinterlands for Indus cities by drawing circles around site locations on a map (as in Fentress 1976: Fig. 7 and Possehl 1993: Fig.2).

8) The materials that I have associated with Mohenjo-Daro (chert), Harappa (steatite), Rakhigarhi (metals), and Dholavira (agate), were almost certainly not the only ones being exported and they may not have even been the most important. They were simply the most obvious and/or probable exports. In addition to steatite, residents of Harappa were likely exporting materials such as vesuvianite-grossular and alabaster.




**Figure 13.10** The primary rock and mineral catchment area for Harappa and the projected distribution network from that city/area for steatite from the "northern" region.

Of all Harappan cities, Ganweriwala was the one most far removed from significant rock and mineral resources. Alluvial fans located about 125 km to the west of the site at the base of the southern Sulaiman Range were nearest stone sources of any kind. Basically, all that could have been acquired from them were siliciclastic sedimentary rocks for grindingstones. Alabaster and chert sources did exist around 100-150 km further westward. Also, some limestone from Harappa appears to have come from the low outcrops in the Jaisalmer area, 150 km to the south of Ganweriwala. Overall, however, the city's

regional-level acquisition options were limited. To represent this, I have placed only brown arrows on Figure 13.11 extending from the southern Sulaiman range and the Thar Desert. Given the regional limitations and its location along what was certainly a major trade and communication route between the upper and lower Indus Basin regions, Ganweriwala's primary catchment area was, largely by necessity, extra-regional in scope.

Rakhigarhi's primary rock and mineral catchment area likely encompassed material sources in the highlands both to its north and to its south. I predict that metals – gold from the Himalayas and copper from the northern Aravalli Range, will be eventually be discovered (or, in the case of copper, confirmed) to have been the major trade goods from that city/zone. These are represented on Figure 13.11 using green arrows. Steatite from sources in the northern Aravalli Range may have also been an important trade good as suggested by analyses of artifacts from Harappa and Mohenjo-daro.

The model presented here greatly simplifies what was assuredly a highly complex system. Nevertheless, it is a practical representation of what probably was the Indus rock and mineral acquisition system's multi-regional structure. The acquisition patterns evident in the assemblage at Harappa conform to the model; but that is to be expected as it was upon them that it is largely based. The question is: Will the patterns at the other Indus Civilization cities similarly conform to those predicted here? The limited work done on the matter so far suggests that they probably will. Based on my own preliminary observations of rock and mineral artifacts (both in-situ and in collections) from each of the other main Indus urban centers, I would provisionally suggest that Harappans at most of those cities were heavily exploiting raw materials from sources in the highland regions adjacent to them. Limited provenience analyses have already confirmed that some materials from each projected catchment zones were being exported to Harappa.

I wish to make it clear that the primary rock and mineral catchment areas for Indus Civilization cities that I have modeled here are economic interaction spheres and not political ones. Each zone, in fact, encompasses multiple distinct cultural phases. Harappans, "Late" Kot Dijians, Northern Neolithic peoples and, very likely, some poorly known Chalcolithic cultures in northern Afghanistan, were all included in Harappa's primary catchment area. Harappan and various non-Harappan cultural phases were similarly encompassed in most of the other projected zones. These economic interaction spheres were joined with one another primarily through inter-regional trade among Indus Civilization peoples within the Indus Valley proper. We know from other lines of evidence that the multi-regional Indus system articulated, to varying degrees, with other interaction systems far to the west of the Greater Indus region. In this study, however, I have yet to positively detect evidence for such contacts at Harappa in the form of rock and mineral artifact provenience patterns. I have a theory, which I discuss next, as to why this may be.

### *A brief consideration of undetected acquisition patterns at Harappa*

Before closing, it may be helpful to take advantage of the broad perspective the above model offers in order to briefly consider some of the acquisition patterns that were *not* detected in this study of Harappa's assemblage. Specifically, I refer to the lack of clear evidence for long-distance external trade with the ancient peoples of Mesopotamia, Iran and Arabia. Earlier I stated that I felt part the reason such evidence failed to be detected was because of the limited number of analyses involving copper and precious metal artifacts, which I believe were the most likely imports from those distant regions. Another part of the reason has to do with Harappa's position within the Greater Indus region.

On Figure 13.12, I have drawn black dashed lines and arrows to represent the most likely routes by




**Figure 13.11** Projected primary rock and mineral catchment areas for the five major Indus urban centers and the probable major raw material distribution networks for those cities/areas.

which finished goods or raw materials from areas outside of the Greater Indus region entered into the Indus Civilization's internal trade system. Note that Harappa, situated as it is in the upper Indus Basin and with its primary catchment area oriented to the northwest, is among the least optimally located urban centers in terms of access to the West Asian trade routes (only Rakhigarhi is in a poorer position). Mohenjo-daro and Dholavira, on the other hand, are the two Indus urban centers whose primary catchments areas the land and sea routes from the west would have first encountered. Therefore, there is

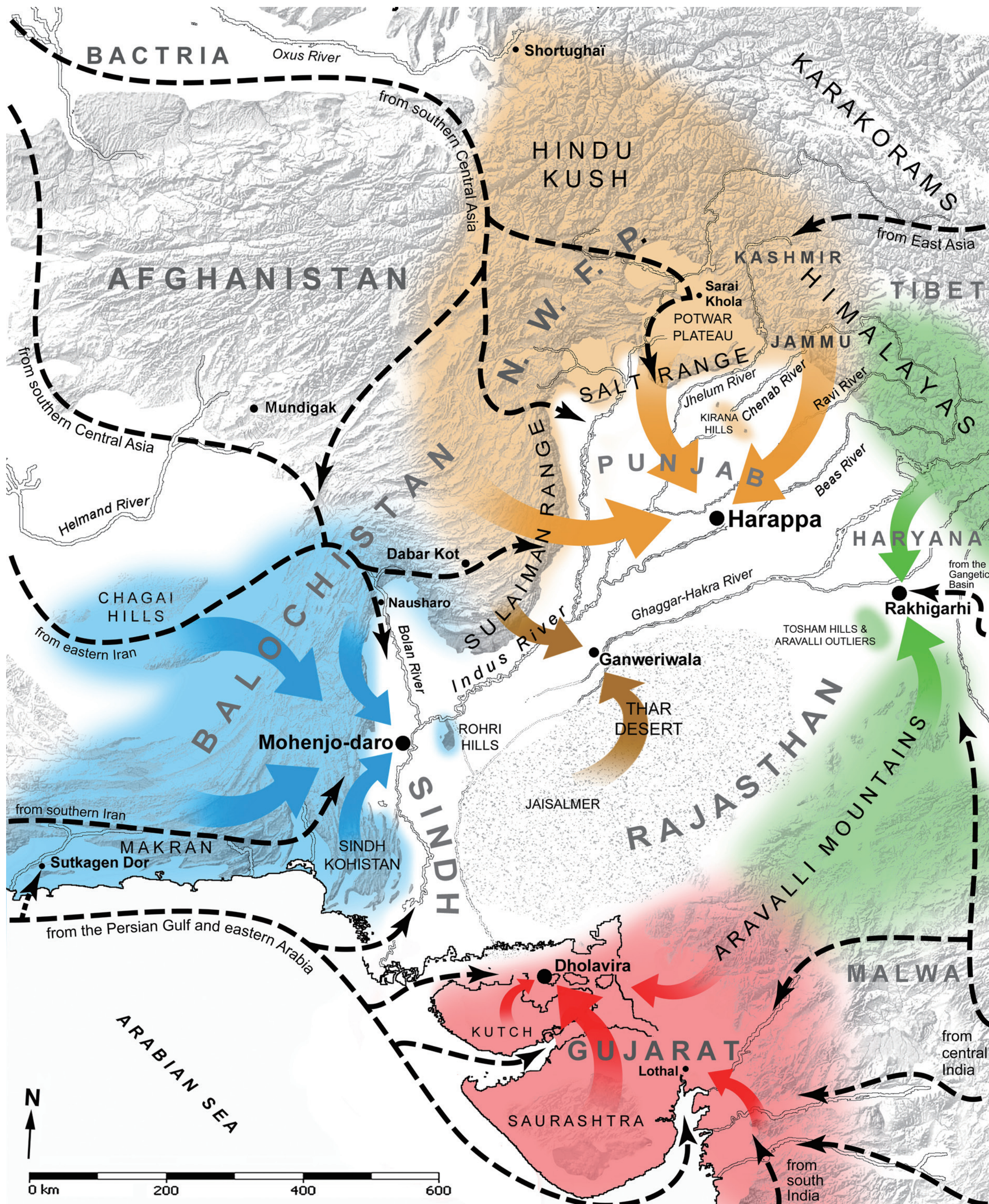



**Figure 13.12** Possible routes by which finished goods or raw materials from areas outside of the Greater Indus region entered into the Indus Civilization's internal trade system.

a far greater chance that evidence for the acquisition of rocks and minerals from sources in Arabia, Iran or Mesopotamia will be found in the assemblages of those cities. Western goods could, of course, have been then transported onwards to consumers at urban centers deeper in the interior like Ganweriwala, Harappa and Rakhigarhi. However, Harappans at those cities may have had access to other, closer sources of the same material varieties. For instance, if we are talking about copper then the residents of Rakhigarhi might have had little need at all for imports because, as I have hypothesized, they had

access to and were exporting that metal from sources within their own primary catchment area. The Pb isotope analyses I have conducted on the handful of copper ores from Harappa suggest that residents there were acquiring those ores from sources both to the west of the Indus Valley (*possibly* Oman) as well as from the northern Aravallis (within the Rakhigarhi zone). Harappans at Dholavira and Mohenjo-daro, having the best access to copper from western sources, might have been using it almost exclusively[9]. When the rock and mineral assemblages of all Indus urban centers are eventually analyzed, we may see that the quantities of many imports (not just copper) at a city decreases or increases with its relative distance to the region where the Indus system articulated with external trade routes. This could explain, in part, why Arabian and West Asian goods have, thus far, failed to be detected at Harappa.

## CHAPTER CONCLUSION

The extensive geologic provenience analyses that were conducted for this study on stone and metal artifacts from Harappa and others sites have helped to generate a new and detailed understanding of resource acquisition patterns and inter-regional interaction during the initial manifestation of urbanized society in South Asia. Overall, most of the rock and mineral acquisition networks in which residents of Harappa were involved appear to have, over time, expanded, contracted and shifted in ways that correspond well with the generally understood and accepted cultural/chronological sequence of late-prehistoric northwestern South Asia. Provenience determinations demonstrate that, during one period or another, people living at the site interacted, either directly or indirectly, with peoples in most every other part of the Greater Indus region. The strongest, earliest and most enduring of the inter-regional relationships residents of Harappa appear to have had were with highland peoples dwelling in areas to the north of Indus Basin. External trade with these and other groups in highland areas directly adjacent to the Indus Valley was an important and continuous aspect of the socio-economic lives of Harappa's residents. Evidence in the site's rock and mineral assemblage for contacts with distant regions such as Arabia and Mesopotamia remains elusive, however.

There is still much work to be done. In the next chapter, I offer a few brief concluding remarks on the main accomplishments of this study and then some thoughts on the future directions that this research might take.

9) Or they might not have. As this book was being finalized, Pb isotope data for artifacts from Dholavira became available that suggests northeastern Gujarat might have been the most important copper source area for residents of that Indus city.

# CHAPTER 14

# CONCLUDING REMARKS

In conclusion, I briefly highlight some of the accomplishments of this study as well as discuss the future directions that this research might take.

## ACCOMPLISHMENTS AND FUTURE DIRECTIONS

Although the acquisition and trade of rock and mineral resources by Indus Tradition peoples has been the subject of a great deal of scholarly attention over the years, prior to this study there were few serious attempts to systematically identify the actual geologic sources of stone and metal artifacts from sites in Pakistan or India. Perhaps the main accomplishment of this study has, therefore, been the advancement of this type of provenience research in prehistoric South Asian archaeology. The large numbers of samples analyzed and the diverse range of rock and mineral varieties examined should provide a solid base for further studies. With regard to the specific materials examined thus far, let me briefly outline some of the future directions I intend to pursue.

Before this study, few scholars had paid much attention to grindingstones. Even fewer had given thought to their potential their sources. I examined all 2586 such artifacts recovered at Harappa and, by comparing them to geologic samples from the highlands in and around the upper Indus Basin, was able to identify the probable source formation of some 70% of them. In addition to continuing to source all newly recovered grindingstones at Harappa, it is my goal to examine those from as many contemporaneous sites in the upper Indus Basin region as possible. Through such studies, which can be done in-situ and non-destructively, I plan to trace in detail the networks through which these difficult-to-transport bulk items were moved hundreds of kilometers from their sources to Harappa.

A great deal has been learned in this study about chert at Harappa but much work remains to be done. I have identified two possible sources – one in the Salt Range and one in Kashmir, for the purple chert-chalcedony used during the site's early phases. Both will need to be field checked. It is now fairly certain that the black-brown chert used during the Early Harappan Period at Harappa came from the Salt Range's Sakesar Formation. The next step will be to analyze samples from across that extensive formation so as to identify the specific source(s) used. My analyses of tan-gray chert from Harappa, Dholavira, Rakhigarhi and Nagwada confirm what many scholars have long assumed – that much of that material likely came from sources in the Rohri Hills of Sindh. There are, however, other tan-gray chert sources in Sindh, Balochistan and the NWFP that eventually will need to be sampled and analyzed.

The steatite provenience study that is the centerpiece of this book is the largest ever conducted outside of the United States. Artifacts from Harappa and seven other sites were compared to geologic samples collected from sources in every major region surrounding the Indus Basin. It was found that Indus Tradition craftspeople mainly utilized steatite from dolomitic occurrences and, contrary to the predictions of many scholars, relatively little of it came from sources in Rajasthan. The majority of the artifacts analyzed from Harappa, Mohenjo-daro, Rakhigarhi and Dholavira appear to have come from sources north of the Indus Basin. Knowing this, efforts will

be made in the future to do more extensive sampling in the NWFP and Jammu and, whenever it becomes possible, to obtain samples from steatite occurrences in northeastern Afghanistan. Sampling excursions to central Balochistan and eastern Arabia will likely be necessary to locate the sources of (respectively) the black steatite used at Mehrgarh and the material to used make the broken seal at Gola Dhoro.

The agate provenience study presented in this book was, to my knowledge, the first ever conducted using INAA. The results were outstanding. They confirmed that Indus Tradition peoples at sites like Harappa and several others in the Indus Valley were utilizing agate primarily from sources in Gujarat. However, it was determined that most of it probably came from occurrences in the eastern Kutch region rather than, as was widely thought, the more famous Ratanpur area deposits in the southeastern part of that state. There were also indications that agate from sources outside of Gujarat was sometimes used. As this study continues, the first step will be to focus on enlarging the geologic sample database to include sources in eastern Gujarat, Saurashtra and central Kutch. Minor but potentially important unsampled occurrences in Sindh, Balochistan and Kashmir will also need to be field checked. Eventually, when agate samples from sources (not proxy sources as was done for this study) in Iran, Afghanistan and Arabia are incorporated into the dataset, it should be possible to examine questions relating to the Harappan agate trade with western Asia in great detail.

Building upon work begun by Vidale and Bianchetti (1997), I was able to identify and document the full extent of vesuvianite-grossular use at Harappa. This rock, which in the past was misidentified as either jade or serpentine, is now known to have been the third most commonly used ornamental stone at the site (after steatite and agate-jasper). The provenience study conducted for this study was the first ever involving this material. Using INAA, fragments from Harappa and Mohenjo-daro were compared to samples from the only known sources in Rajasthan, Balochistan and the NWFP and found to have originated in the latter two regions. The next step will be to similarly analyze the vesuvianite-grossular ornaments that I have recently identified at the Indus sites of Dholavira and Lothal in Gujarat.

Strontium and sulfur isotope analyses of alabaster artifacts and source samples indicted that residents of Harappa were utilizing raw material from multiple occurrences in the Salt Range, the NWFP and northern Balochistan. A group of artifacts that had highly elevated Sr isotope values seem to have come from a source or sources not analyzed. Identifying that source(s), which there is a strong possibly might be located in the western Himalayas (Jammu and Kashmir and/or Hazara), will be a high priority in the future.

A large and varied set of limestone artifacts from Harappa was compared source samples using both INAA and a new technique involving mass spectrometry. Among the findings was that banded yellow-brown sandy limestone ringstones weighing in excess of 100 kg were probably being transported to Harappa from a source over 800 km to the south near Dholavira in northern Kutch. In the future, additional sampling and analysis will need to take place in order to, hopefully, better differentiate Kutch limestones from similar looking ones found in the Jaiselmer region. Also a third potential source of this distinctive material type in the Kirthar Range will need to be incorporated into the geologic dataset.

Pb isotope assays of lead, silver and/or copper artifacts from Harappa and other sites permitted many longstanding questions regarding the acquisition and trade of those metals to be addressed. Among the findings was that residents of Harappa were obtaining various lead ores from deposits in Jammu and Kashmir, Balochistan and at least one other, unknown source. Copper ores at Harappa seem to have come from northern Rajasthan as well

as other sources that, although hard to pin down, probably lie west of the Indus Valley. The unknown lead source and vague proveniences of the copper artifacts highlight the need to conduct more extensive sampling and analysis of the potential sources of those metals.

In addition to a series of successful provenience studies, one thing I hope can be counted among the accomplishments of this book is the infusion of a modicum of geologic reality into the general discussion of prehistoric rock and mineral acquisition and trade in the Greater Indus region. I strove to demonstrate that, among other things, it is not only important to be cognizant of where certain raw materials are found but also of where they are not and why. For example, although I was unable to actually visit the Chagai Hills of Balochistan, by looking closely at the published accounts of the geology there and critically looking at the environment in which the mineral lazurite forms, it was possible to, if not to actually disprove, at least to show that is tremendously unlikely that lapis lazuli could occur in that region. I also attempted to show that it was necessary to be aware that the quality of certain kinds of stone can vary considerably from source to source. Materials like chert, steatite and agate are fairly widespread but good quality chert, steatite and agate (i.e, that which Harappans would have found suitable for use) are much harder to come by. What's more, the properties that determine quality are not always readily apparent. Only through experimental heating of steatite samples from occurrences across the Greater Indus region did it become clear that the material at the majority of them would not become white when fired, which is a property Harappans sought. This explains why they were ignoring were so many accessible sources of seemingly excellent quality stone and focusing on a very specific few. Ultimately, what I tried to do in this book was move beyond past studies that simply listed published locations of rock and mineral resources and assumed (without looking critically at either the original published reference or the material reported to occur) that ancient peoples were utilizing the nearest and/or most accessible sources.

Being given access to rock and mineral artifacts from a major archaeological site like Harappa was an honor and a privilege, not to mention a rare opportunity. Although it was impossible for me to analyze each of the 56,350 stone or metal objects recovered up to the point this project began, I endeavored to make full use of the assemblage by conducting a thorough inventory of it, categorizing all of the artifacts in a systematic manner by material variety, attaching a provisional spatial and temporal context to each one, quantifying the whole thing and then examining if and how it varied across time and space. I feel that this was an accomplishment on the order of any other achieved in this study. Only by doing this was it revealed how, while the basic suite of rocks and minerals used at Harappa largely remained constant from period-to-period and from area-to-area, there were certain materials, notably vesuvianite-grossular and "Ernestite," which seem to have been utilized during specific periods and controlled by residents in certain parts of the city.

Much work remains to be done on artifacts from Harappa among the eight rock and mineral varieties that were the subjects of provenience analyses detailed in this book. The sub-assemblages for grindingstones and lead were examined in their entirety but more such artifacts are certain to be recovered. Roughly half of Harappa's limestone artifacts were analyzed but some of the minor varieties still need to be examined. Some 75 tan-gray chert artifacts from Period 3C must still be analyzed just to achieve a 1% sample of that extensive sub-assemblage. The steatite provenience study is deficient with regard to samples from Period 1. Agate artifacts from all periods and parts of the site need analyzed. I would like to achieve a 10% sample of vesuvianite-grossular artifacts overall. Twelve additional alabaster artifacts need to be analyzed to achieve a 10% sample of that sub-assemblage.

There are a number of rock and mineral varieties at Harappa that are suitable subjects for large-scale geologic provenience analyses but which have not yet been studied in this way or have only been subjected to preliminary examinations. I am happy say the large and difficult task of identifying the sources of copper-alloy artifacts from Harappa is currently taking place under the direction of Dr. Mark Kenoyer at the University of Wisconsin-Madison. Among other the rock varieties that offer the greatest potential for future provenience studies is basalt, on which I have already done limited work. Serpentine, red and green jaspers, and amazonite are also materials that can perhaps be successfully sourced. However, I am most optimistic about future provenience studies involving Harappan gold, which was probably derived from numerous geologically distinct sources located around the Greater Indus region and beyond.

Finally, I hope in the future to expand my provenience research beyond both Harappa and the range of issues addressed in this book. To some extent, this has already begun. Artifacts from a dozen other sites were analyzed and presented here and materials from several additional ones are currently being processed. I am presently conducting broad-scale studies of the stone and metal artifact assemblages of Dholavira and Rakhigarhi. I hope to initiate similar studies on materials from Mohenjo-Daro and Ganweriwala shortly. However, some of the most interesting and important work in the future will be done at smaller sites, particularly those along the peripheries of the Indus Civilization where Harappans would have been directly interacting with non-Harappan peoples. I have shown that it was from such regions and, possibly, in this manner that Indus peoples acquired many of the rock and mineral resources that they used. At Harappa, it is only possible to detect and examine the end result of those inter-societal contacts. The best opportunity to find and study evidence of direct interaction with non-Harappan peoples is regions like Gujarat at sites like Gola Dhoro where peoples of a distinct indigenous cultural phase are documented to have existed alongside Harappans (Bhan *et al.* 2004). It is in such regions and at such sites that phenomena like trade diasporas and colonialism, or models of interaction like "world-systems" theory, can be, and have recently been (Chase 2007), examined and evaluated. I hope to one day examine those and related issues along the Indus Civilization's "northern borderlands" by studying the dynamics of rock and mineral acquisition and exchange in that region. However, before the types of questions that are now beginning to be addressed in Gujarat can be addressed in the north it will be necessary for a great deal of new data to be collected. This will required detailed, question-oriented excavation (or re-excavation) at Harappan sites in that region such as Ropar (Sharma 1982), Manda (Joshi and Bala 1982), Musa Khel (Dani 1971: 32) and Hisham Dheri (ibid.: 31).

In the meantime, there are untold number of stone and metal artifacts in collections from excavations and surveys of Early Harappan and Harappans sites across northwestern South Asia just waiting to be analyzed using the techniques demonstrated in this book to be effective. The geologic datasets against which to compare such artifacts, although still being augmented, are now basically in place. In collaboration with scholars at institutions in India, Pakistan and elsewhere, I hope to embark on a broad-scale, long-term program aimed at identifying the sources of as many different varieties of rock and mineral artifacts from as many sites, large and small, as is possible. By doing so, we should be able to generate a picture of resource acquisition and inter-regional interaction in the Greater Indus region that is unprecedented in its detail and accuracy.

# APPENDIX 1.1

## PROVENIENCE VS. PROVENANCE

"Provenience" and "provenance" are closely related words. I have always understood the former term to mean a thing's *place of origin* or *source* and the latter term to mean a thing's *history* going back to and including it's origin or source. Provenance is frequently used by museum curators and art historians when discussing an object's or artwork's chain of ownership from, if possible, the time of it's discovery or creation to the present day. In archaeology, provenience can refer to two somewhat different things. There can be "archaeological provenience" (almost always referred to simply as provenience), which is both the site at which an artifact is recovered and its original location in three-dimensional space at said site, and then there can be "source provenience", which is the geographic location or area from which the raw material (rock, mineral, wood, shell, paste, temper, whatever) used to fashion the object in question was acquired. Because I was attempting to locate the raw material sources of stone or metal artifacts, I decided be a little more specific and call my work a "geologic provenience" study.

I felt confident that I was using the term provenience correctly. After all, it is in Weigand and others (1977: 24) often cited paper that the basic assumption of raw material sourcing was first made explicit as the "*Provenience* Postulate" (emphasis added). Of course I was aware from reading the literature pertaining to sourcing studies that the term provenance was used more frequently than provenience, but for the longest time I thought of this as simply an alternate spelling, perhaps one used more commonly in the UK and Europe. Then some people started to tell me that this was not an issue like *color vs. colour*. Instead, they said that I was, supposedly, using the term provenience incorrectly. But no one could tell me when, why or who decided that provenance was the correct usage, only that it was the convention. Around the time I was finalizing my dissertation I read the book Geoarchaeology by Rapp and Hill (2006) in which they plainly state (ibid: 222) that provenience is an artifact's archaeological context and provenance is an artifact's raw material source . Not really convinced but wanting to be correct, I hit ctrl-H and replaced all of the proveniences in the text of my thesis with provenances. At my dissertation defense, however, one of my committee members said that provenance was actually the incorrect usage and bluntly told me that he would not sign my thesis unless I changed it back to provenience. Since I agreed with him anyway (and wished to graduate) I happily did so.

For this book, I will continue to refer to my work as geologic provenience analyses of stone and metal artifacts. I realize that this swimming against the stream. A quick perusal of titles, abstracts and keywords using the online search engines for journals like Archaeometry, The Journal of Archaeological Science, and Geoarchaeology clearly shows that the provenance is overwhelmingly favored over provenience in published articles about artifact sourcing studies. Even so, the issue is still debated[1)] and the latter term is still sometimes used by researchers (see Grave *et al*. 2009 for a recent

1) See the following two entries in archaeologist K. Kris Hirst's blog: [http://archaeology.about.com/b/2006/05/16/provenience-provenance-lets-call-the-whole-thing-off.htm] and [http://archaeology.about.com/b/2006/05/09/provenience-or-provenance-a-poll.htm]

example). I am certain that I will be continue to be told by some (perhaps many) people that my usage of the word provenience is incorrect. But it makes much more sense to me and I don't think there will be any serious confusion because of it as to the nature of the research I am actually doing.

# APPENDIX 2.1

# MAJOR DIVISIONS OF GEOLOGIC TIME

| EON | ERA | PERIOD | | EPOCH | Age in million years before present |
|---|---|---|---|---|---|
| | | | | | Present |
| Phanerozoic | Cenozoic | Quaternary | | Holocene | 0.01 |
| | | | | Pleistocene | 1.6 |
| | | Tertiary | Neogene | Pliocene | 5.3 |
| | | | | Miocene | 23.7 |
| | | | Paleogene | Oligocene | 36.6 |
| | | | | Eocene | 57.8 |
| | | | | Paleocene | 66.4 |
| | Mesozoic | Cretaceous | | | 144 |
| | | Jurassic | | | 206 |
| | | Triassic | | | 245 |
| | Paleozoic | Permian | | | 286 |
| | | Carboniferous | Pennsylvanian | | 320 |
| | | | Mississippian | | 360 |
| | | Devonian | | | 408 |
| | | Silurian | | | 438 |
| | | Ordovician | | | 505 |
| | | Cambrian | | | 570 |
| Precambrian | Proterozoic | | | | 2500 |
| | Archean | | | | 3800 |
| | Hadean | | | | 4450 |

# APPENDIX 2.2

## REMARKS AND OBSERVATIONS ON THE ATTRITION OF STONE IN RIVERBEDS

Some scholars have suggested that certain varieties of stone used by Indus peoples may have been procured from secondary contexts, such as the beds of rivers flowing from mountain ranges, rather than from in situ geologic formations of those materials (see citations on p. 36). For example, a single, water-rounded pebble of lapis lazuli discovered at the Harappan outpost of Shortughaï in northern Afghanistan promoted the excavator of the site to speculate that some procurement activities involving that stone may have been "no more than gathering lapis in the riverbed" (Francfort 1985: 129). The riverbed in question is that of the Kokcha. It's upper reaches transect the zone where lapis lazuli occurs in the Badakshan district and the site of Shortughaï is near (5 km away) its terminal confluence with the Amu Darya (Francfort 1984b: 302). One may wonder at what point along the Kokcha's several hundred kilometer length was the pebble collected? Lapis lazuli is not a particularly hard (Mohs 5 to 6) or tough stone. It seems unlikely that a piece of it could have been rolled very far in a riverbed among tough boulders of granite and limestone before it was completely obliterated. And what about other types of softer or harder materials? Although I conducted no formal studies of the attrition rates of different kinds of stone in riverbeds (see Werrity 1992 for such as study), I tried to keep this issue in mind as I visited raw material sources and river drainages across the Greater Indus region.

In early 2001, I visited the Bannu Archaeological Project's (BAP) excavations at Lewan (Appendix 2.2 Figure 1 A) and noted among the lithic debris visible on site's surface numerous pieces of chert and jasper with rounded, weathered exteriors (Appendix 2.2 Figure 1 B). These were clearly fragments of water-worn cobbles/pebbles. When discussing potential sources of raw material for the lithic industries at Lewan and other prehistoric settlements in the western Bannu Basin, archaeologists working there have pointed to alluvial contexts in the "immediate locality" of those sites (Allchin 1981: 234), i.e., the conglomerate fans at the base of the Waziristan Hills or the beds of the region's many intermittent streams and rivers (Morris et al. 2001: 131). However, when BAP member Justin Morris and I traveled from Lewan to the nearby bed of the Tochi-Gambila river system in order to collect samples of chert/jasper (Appendix 2.2 Figure 1 C) we found very little material at all (as I recall, we came away with only a single palm-sized pebble of grayish chert). Now it's true that we didn't search that long (perhaps an hour) and that the bed of river was dry and dusty (if it had been wet it would have certainly been much easier to spot chert/jasper pebbles). Under better conditions and with more time, ancient peoples with greater experience than we would have almost certainly been more successful. Even so, the Tochi-Gambila river system, at least at the point on it where Justin Morris and I searched, is not exactly brimming chert or jasper. Perhaps the richer source areas lay closer to or within the hills of Waziristan, which were visible from the bed of the Tochi, 12 km to the west (Appendix 2.2 Figure 2).

Later that same year, while conducting geologic sampling in North Waziristan, I visited three jasper outcrops in the region that lay some 50 to 70 km due west of the Bannu Basin sites (Appendix 2.2 Figure 3). Red jasper at occurs at Barzai (Appendix 2.2 Figure 4 A; see also Figure 6.3 A & B) and large boulders of the material erode directly into the adjacent stream

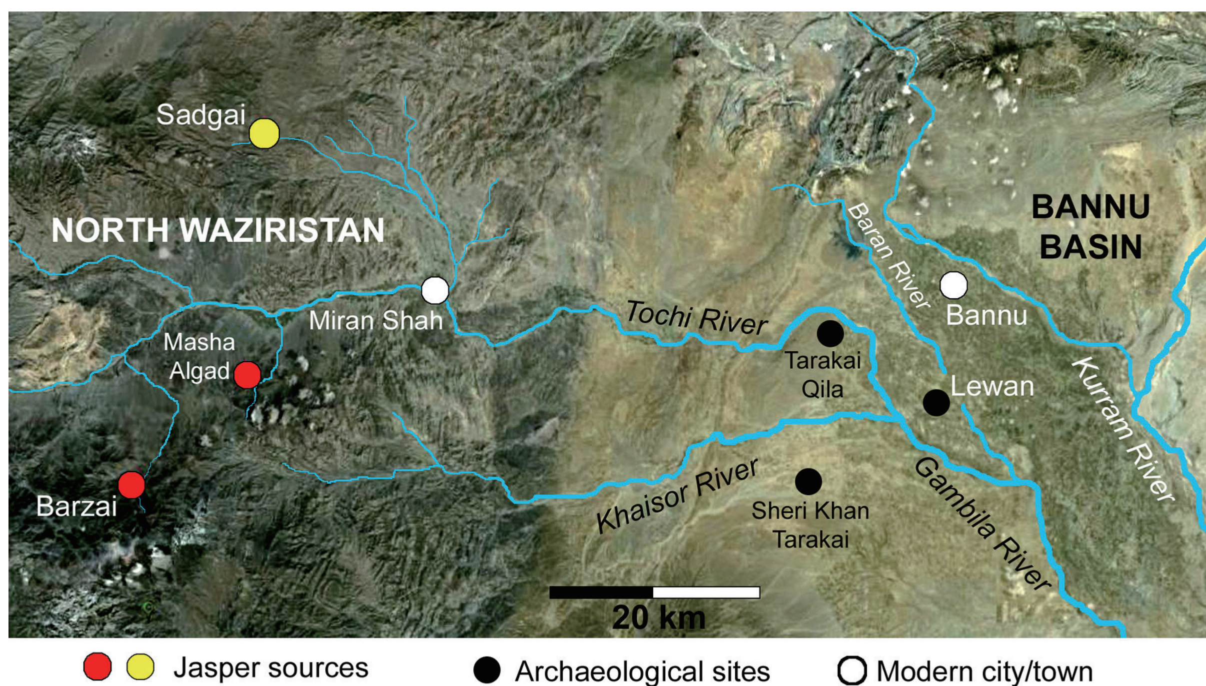



**Appendix 2.2 Figure 1.1** **[A]** Bannu Archaeological Project excavations at the site of Lewan. **[B]** A red jasper pebble fragment on the surface of Lewan. **[C]** Searching for chert and jasper in the bed of the Tochi River.

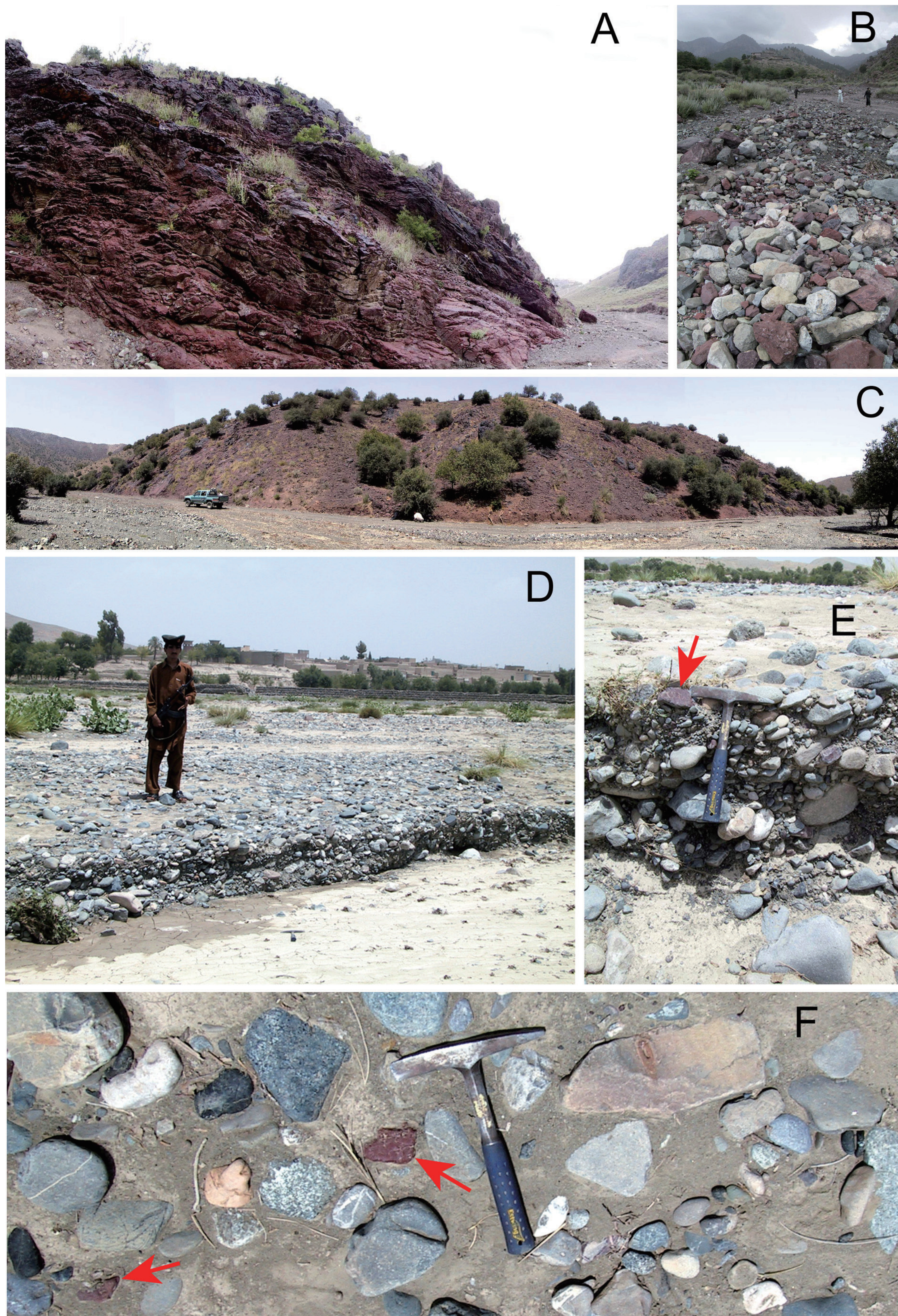
bed or nala (Appendix 2.2 Figure 4 B). Another red jasper outcrop is found at Masha Alga (Appendix 2.2 Figure 4 C) and brecciated jasper-chalcedony occurs at Sadgai (see Figure 6.3 C & D). Importantly, the nalas along which each of these occurrences are located eventually drain into the Tochi River. We had to drive our jeep along these intermittent stream beds to get to and from the sources. As we drove away from the outcrops, the size and amount of jasper fragments visible in the nalas dropped of quickly and, in fact, became, fairly rare after only a few kilometers. By the time I walked a transect of the Tochi River bed (Appendix 2.2 Figure 4 D) just east of the town of Miran Shah (this was still well within the Waziristan



**Appendix 2.2 Figure 1.2** Looking toward the hills of North Waziristan from the bed of the Tochi River.




**Appendix 2.2 Figure 1.3** Map of North Waziristan and the western Bannu Basin showing the archaeological sites, geologic sources, modern towns and rivers discussed in this appendix.




**Appendix 2.2 Figure 1.4** Observations of jasper in North Waziristan. **[A]** The jasper outcrop at Barzai. **[B]** Jasper boulders in the nala adjacent to the Barzai outcrop. **[C]** The jasper outcrop at Masha Alga. **[D]** Searching for jasper in the Tochi River bed just east of Miran Shah. **[E]** A jasper fragment (arrow) in the Tochi near Miran Shah. **[F]** More red jasper fragments (arrows) at the same location.



**Appendix 2.2 Figure 1.5** A water-rolled steatite fragment from the streambed directly below the steatite deposit at Daradar, Kurram Agency, FATA.

Hills, around 45 km west of Lewan), I was only able to find a few fragments of jasper (Appendix 2.2 Figure 4 E & F). Although cursory, I feel fairly confident in this qualitative assessment as it was done not long after a rain and the red jasper fragments I saw stood out prominently.

Based these observations and others, my conclusion is that alluvial fans or riverbeds at the bases of mountain ranges are good sources only for tough materials like sandstone, quartzite and granite. Although stone like chert and jasper can also sometimes be found in such contexts, to have a reliable supply of large, good quality pieces of those raw materials it is necessary to travel fairly close to the original source. For softer or more fracture-prone types of rock it's a non-starter. To reach the Daradar steatite deposit (see Figure 7.18) in the Kurram Agency, FATA, I had to travel the last several kilometers up a steep boulder filled streambed. It was only within sight of the source (less than a 100 meters from it) that I began to observe water-rounded pieces of steatite (Appendix 2.2 Figure 5). If you're going to travel that far you may as well go all of the way. Ancient peoples making the arduous journey up the Kokcha River Valley in order to acquire a valuable stone like lapis lazuli certainly would have collected water-rolled pebbles of the material whenever they encountered them. It is highly likely that such opportunistic procurement happened relatively near the actual deposits and that the ancient peoples would have then continued on to the mining areas themselves.

# APPENDIX 3.1

## MOHS' MINERAL HARDNESS SCALE

| *Hardness* | *Mineral* |
|---|---|
| 1 | Talc |
| 2 | Gypsum |
| 3 | Calcite |
| 4 | Fluorite |
| 5 | Apatite |
| 6 | Orthoclase Feldspar |
| 7 | Quartz |
| 8 | Topaz |
| 9 | Corundum |
| 10 | Diamond |

# APPENDIX 4.1

# X-RAY DIFFRACTION ANALYSES OF HARAPPAN ROCK AND MINERAL ARTIFACTS - MAJOR AND MINOR PHASES

## (*MINOR PHASES DETERMINED BY EMPA)

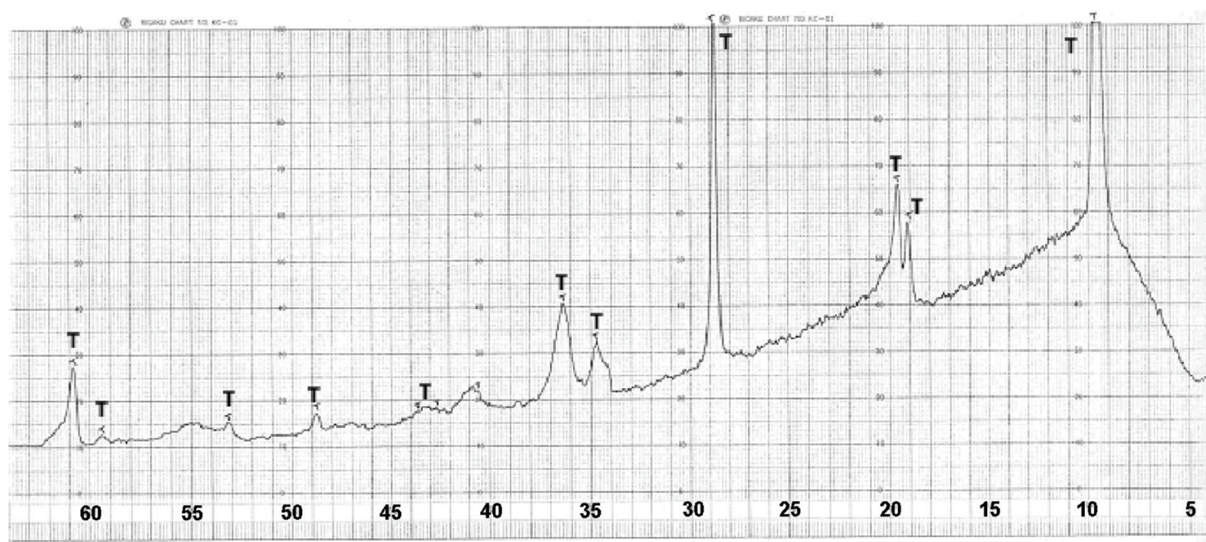
| *Artifact* | *Description* | *Major Phase* | *Minor Phase(s) / [SG]* |
|---|---|---|---|
| H2000/9999-108 | alabaster fragment | Gypsum | |
| H2000/9999-131 | alabaster fragment | Gypsum | |
| H95/4943-8 | copper mineral | Malachite | |
| H90/3126-1 | copper mineral | Malachite | |
| H90/3022-98 | copper mineral | Malachite | |
| H90/2070-12 | copper mineral | Chalcocite | |
| H90/3008-13 | copper mineral | Chalcocite | |
| H90/3008-14 | copper mineral | Chalcocite | |
| H94/4999-529 | copper mineral | Chalcocite | |
| H2000/2090-49 | "Ernestite" | Mullite | quartz, rutile, hematite, zircon* |
| H2000/3317-2 | "Ernestite" | Mullite | cristobolite, titanohematite*, zircon*, phosphate* |
| H2000/3317-3 | "Ernestite" | Mullite | cristobolite, titanohematite*, zircon* phosphate* |
| H2000/3317-4 | "Ernestite" | Mullite | quartz, rutile, hematite |
| H2000/9999-81 | green pebble frag. | Quartz | albite* |
| H90/2076-6 | green pebble frag. | Quartz | epidote*, albite*, sphene* |
| H90/3000-30 | green pebble frag. | Quartz | epidote, rutile* |
| H90/3207-14 | green pebble frag. | Quartz | felspar*, epidote*, albite* |
| H98/8499-351 | green pebble frag. | Quartz | albite* |
| H88/182-14 | green pendent | Nephrite (tremolite) | chromite |
| H2000/9999-126 | green rock fragment | Quartz | tremolite |
| H97/6977-7 | green rock fragment | Fluorite | |
| H96/6303-4 | green rock fragment | Prehnite | |
| H2000/9999-92 | green rock fragment | Quartz | |
| H95/4960-88 | green rock fragment | Quartz | |
| H2000/8990-1 | green rock fragment | Quartz | |
| H94/4999-213 | green rock fragment | Turquoise | |
| H2000/9999-87 | green rock fragment | Vesuvianite | [SG = 3.33] |
| H2000/9999-88 | green rock fragment | Vesuvianite | [SG = 3.29] |
| H2000/9999-89 | green rock fragment | Vesuvianite | [SG = 3.32] |
| H2000/9999-90 | green rock fragment | Vesuvianite | grossular / [SG = 3.32] |
| H2000/9999-93 | green rock fragment | Vesuvianite | [SG = 3.28] |
| H90/2076-7 | green rock fragment | Vesuvianite | [SG = 3.23] |

| *Artifact* | *Description* | *Major Phase* | *Minor Phase(s) / [SG]* |
|---|---|---|---|
| H90/2080-1 | green rock fragment | Vesuvianite | grossular, clinochlore / [SG = 3.28] |
| H90/3000-31 | green rock fragment | Vesuvianite | [SG = 3.23] |
| H90/3011-153 | green rock fragment | Vesuvianite | clinochlore [SG = 3.29] |
| H90/3200-36 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.19] |
| H90/3208-147 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.29] |
| H90/3220-4 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.31] |
| H94/4374-19 | green rock fragment | Vesuvianite | [SG = 3.27] |
| H94/4999-4 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.28] |
| H94/4999-5 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.27] |
| H95/4922-79 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.29] |
| H95/4922-81 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.32] |
| H95/5760-54 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.23] |
| H95/5764-74 | green rock fragment | Vesuvianite | clinochlore / [SG = 3.26] |
| H96/6958-41 | green rock fragment | Vesuvianite | grossular, clinochlore / [SG = 3.32] |
| H98/8499-353 | green rock fragment | Vesuvianite | clinochlore* [SG = 3.32] |
| H94/5310-36 | green rock fragment | Clinochlore | vesuvianite / [SG = 2.98] |
| H96/7129-1 | green rock fragment | Clinochlore | vesuvianite / [SG = 3.16] |
| H2000/9999-91 | green rock fragment | Grossular | vesuvianite*, clinochlore / [SG = 3.45] |
| H94/5106-8 | green rock fragment | Grossular | vesuvianite / [SG = 3.45] |
| H94/4999-23 | green rock fragment | Lizardite | |
| H89/2006-159 | green rock fragment | Lizardite | |
| H2000/9508-2 | green bead | Clinochrysotile | |
| H96-7730-15 | red bead | Kaolinite | hematite |
| H2000/9999-77 | lapis Lazuli fragment | Lazurite | calcite |
| H2000/9999-74 | lapis Lazuli fragment | Lazurite | calcite |
| H90/3011-1 | lead mineral | Galena | |
| H2000/2102-1726 | lead mineral | Galena | stibnite |
| H2000/2226-111 | lead mineral | Galena | stibnite |
| H2000/9999-73 | lead mineral | Galena | stibnite |
| H90/8857-1 | lead mineral | Cerrusite | anglesite |
| H99/8755-152 | lead mineral | Cerrusite | anglesite |
| H2000/2139-141 | lead mineral | Cerrusite | anglesite |
| H90/3193-6 | lead mineral | Massicot | |
| H94/5530-13 | limestone fragment | Calcite | |
| H2000/9999-122 | ochre fragment | Goethite | |
| H2000/2227-65 | ochre fragment | Hematite | |
| H90/3073-34 | ochre fragment | Hematite | |

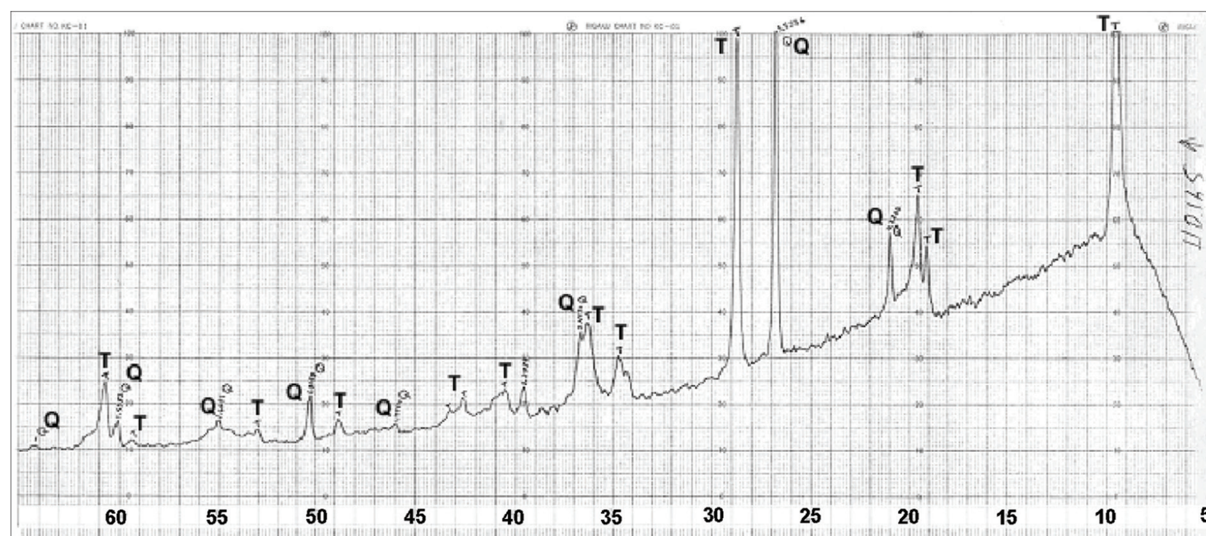
# APPENDIX 4.2

## REPRESENTATIVE XRD SCANS

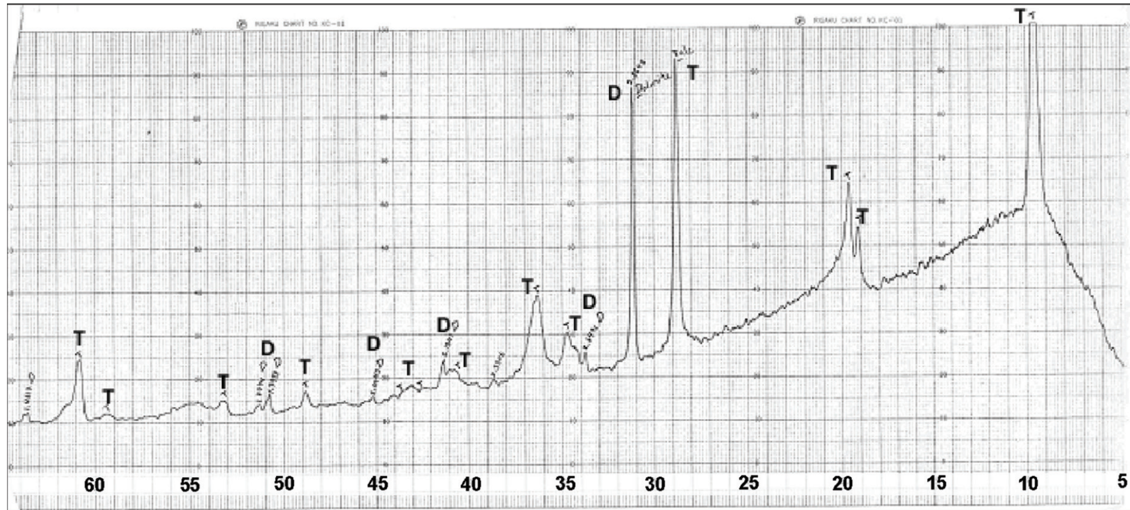
**A**. Steatite fragment H2000/2084-1, Talc (T = talc peak).



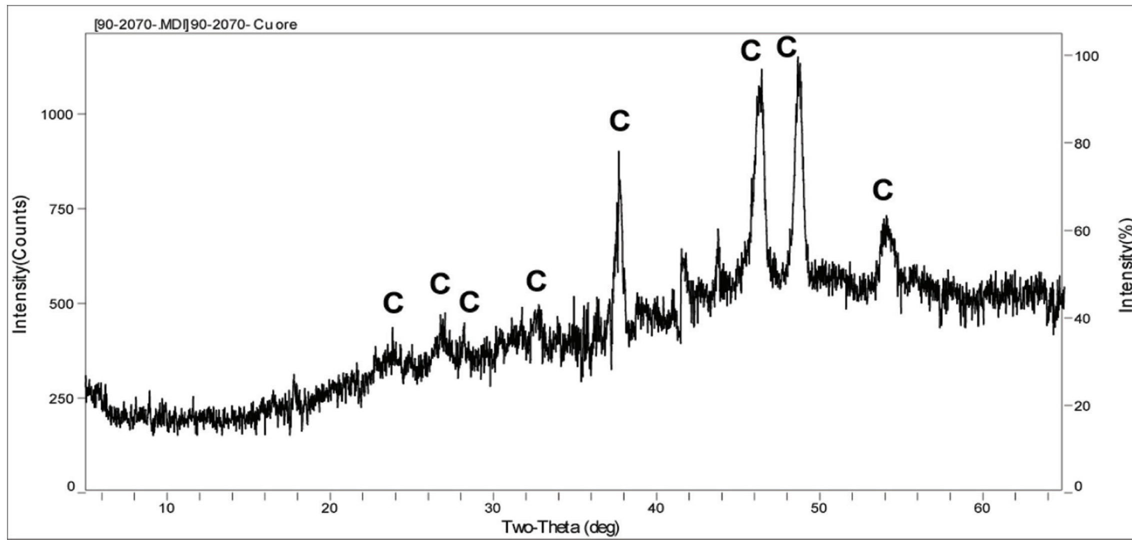

**B**. Steatite fragment H2000/8983-3, Talc (T) with Quartz (Q = quartz peak).



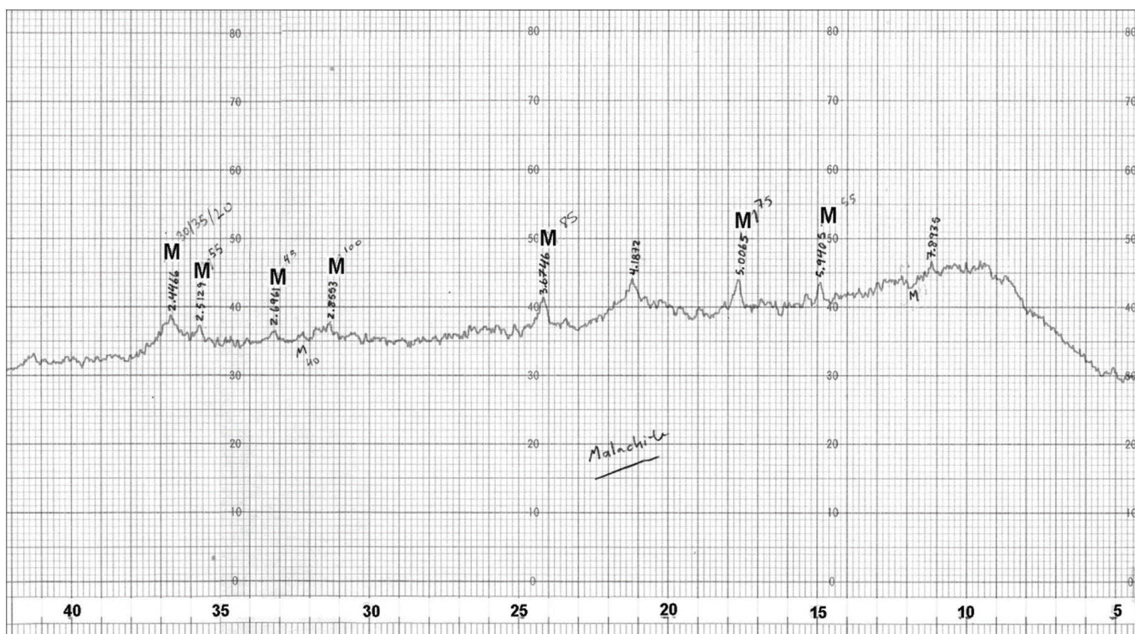
**C**. Steatite fragment H95/5729-99, Talc (T) with Dolomite (D = dolomite peak).



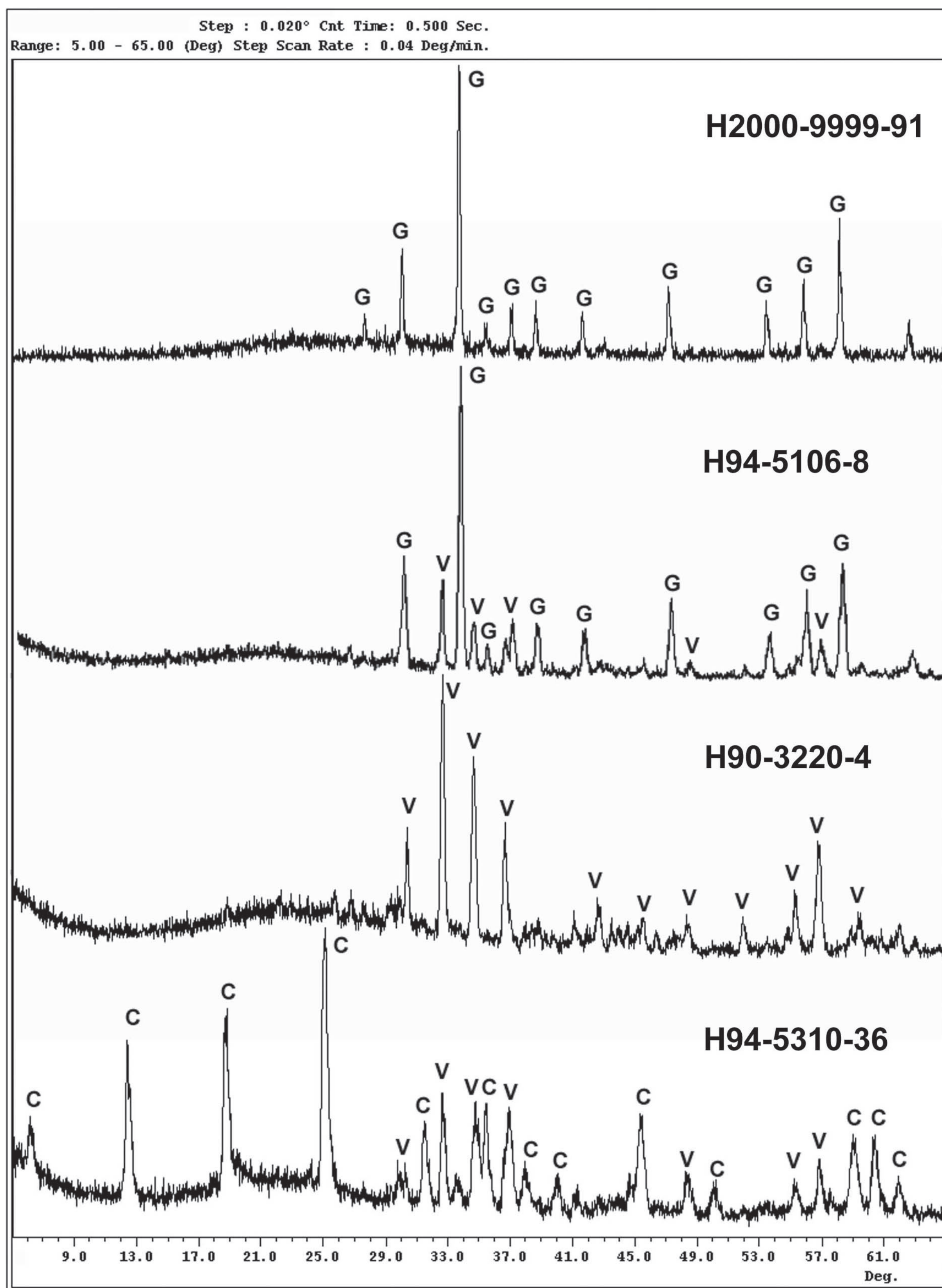

**D**. Copper ore fragment H90/2070-12, (C = Chalcocite peak).



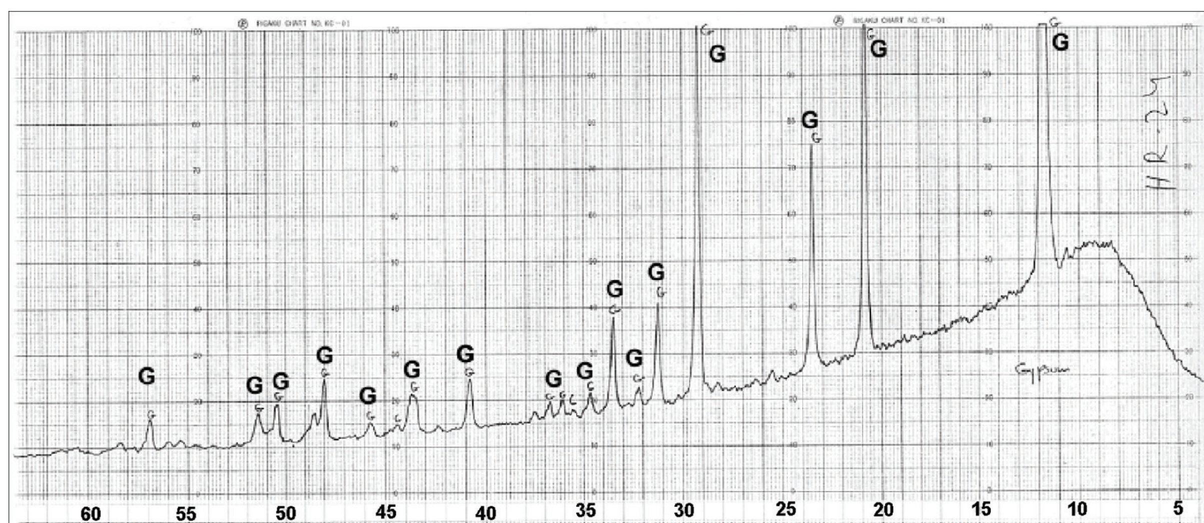

**E**. Copper ore fragment H95/4943-8, (M = Malachite peak).



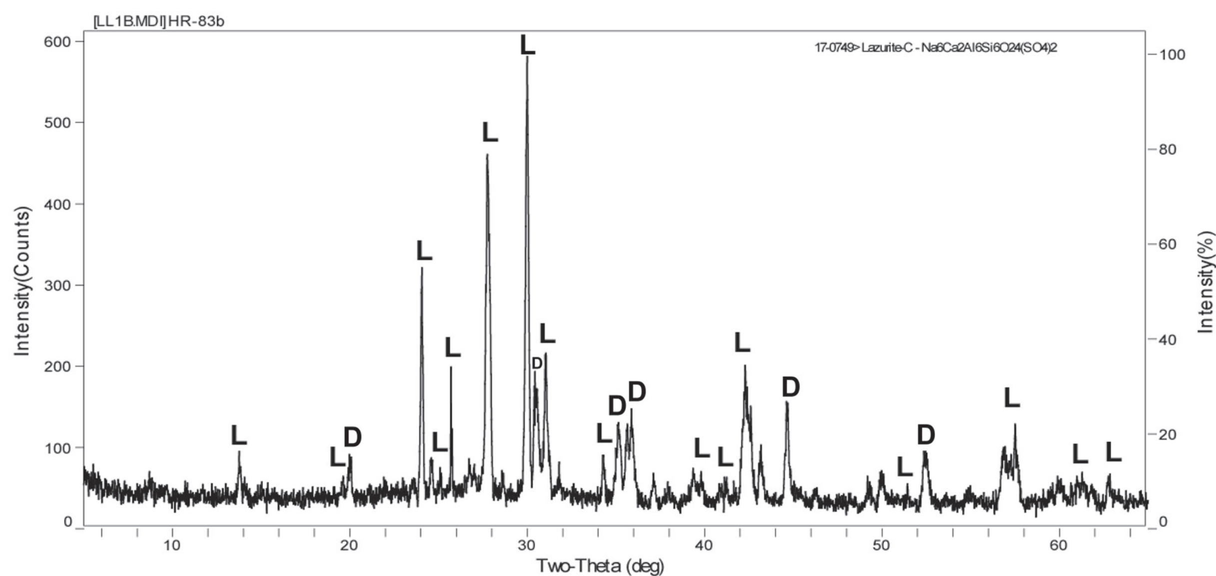
**F**. Composite of four XRD scans of vesuvianite-grossular garnet fragments, (G = Grossular peak, V = Vesuvianite peak. C – Chlorite peak).



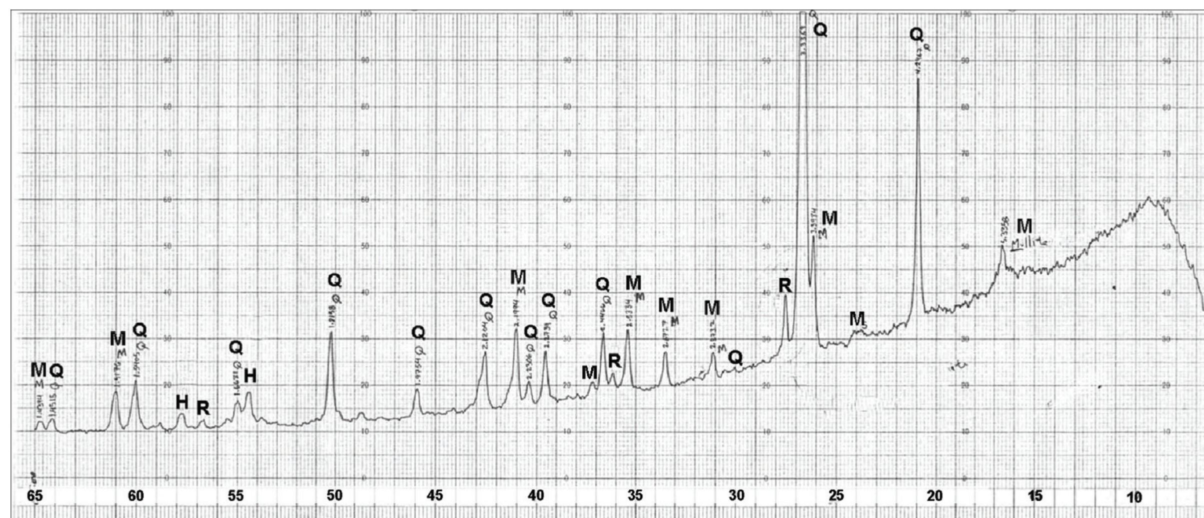
**G**. Alabaster fragment H2000/9999-130, (G = Gypsum peak).



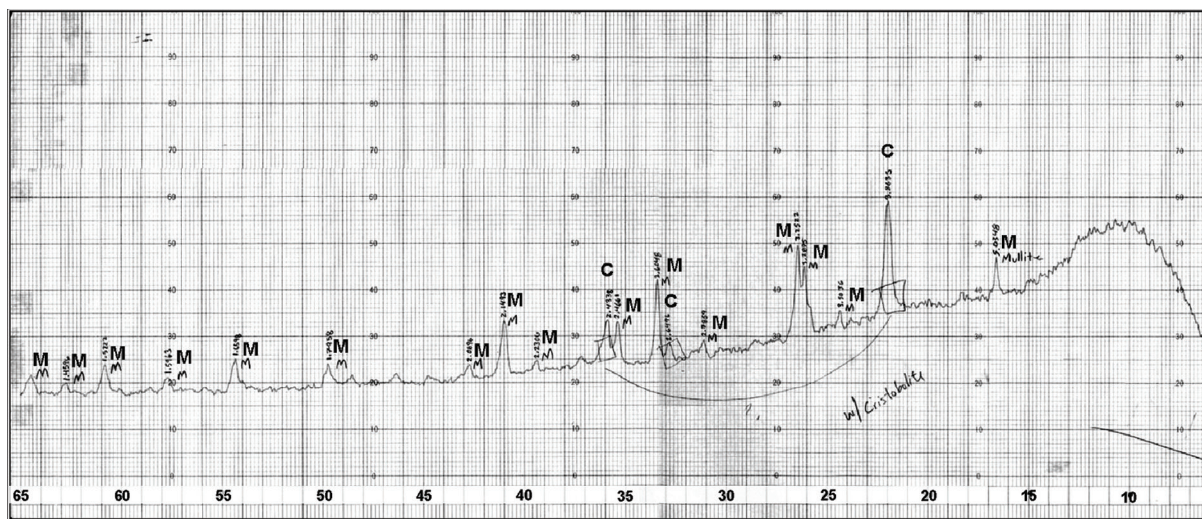
**H**. Lapis lazuli blocklet H2000/9999-77, (L = Laurite peak, D = Diopside peak).



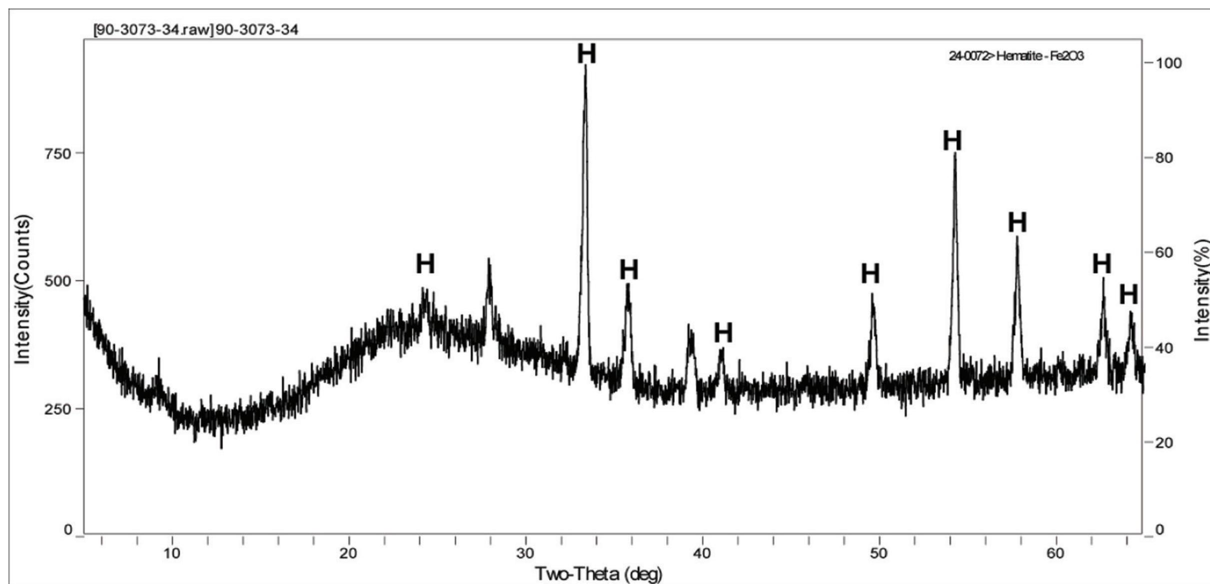

**I**. "Ernestite" fragment H2000/3317-4, (Q = Quartz peak, M = Mullite peak, R = Rutile peak, H = Hematite peak).



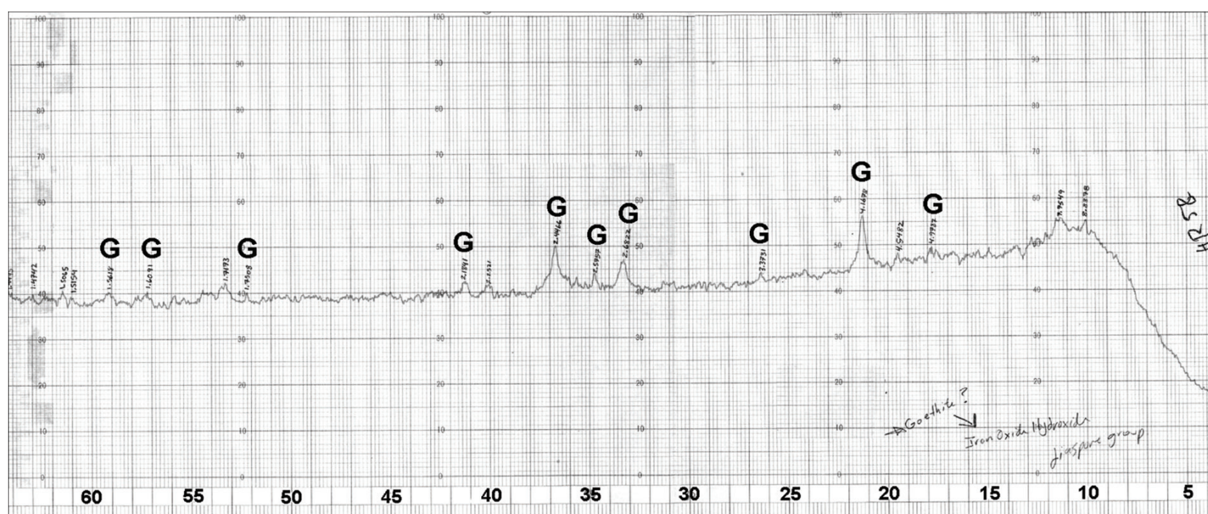
**J**. "Ernestite" fragment H2000/3317-3, (M = Mullite peak, C = Cristobalite peak).



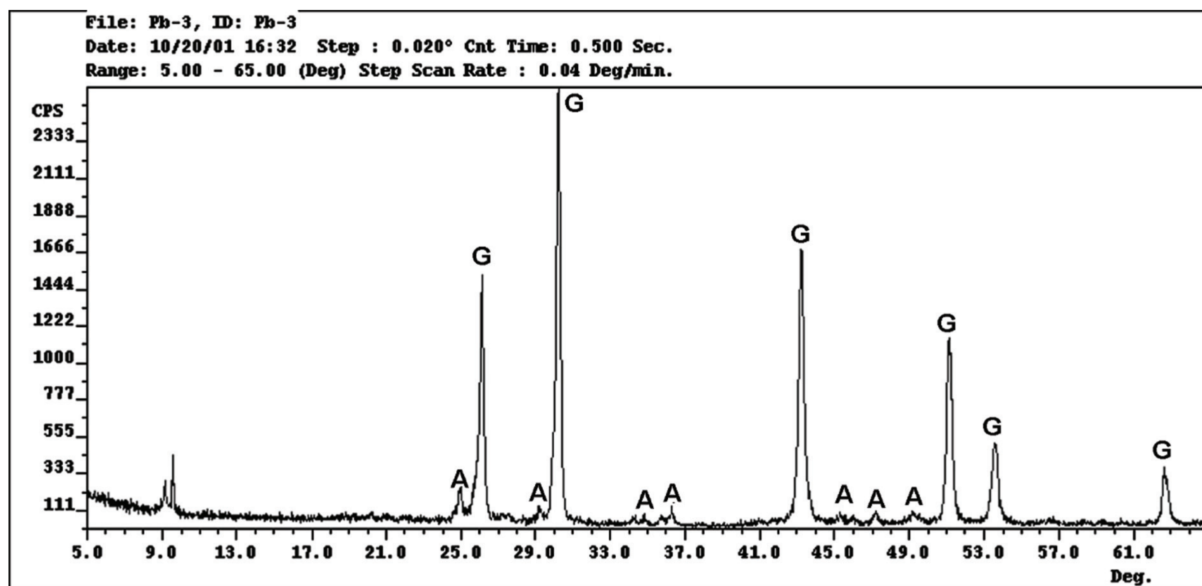

**K**. "Ochre" fragment H90/3073-7,4 (H = Hematite peak).



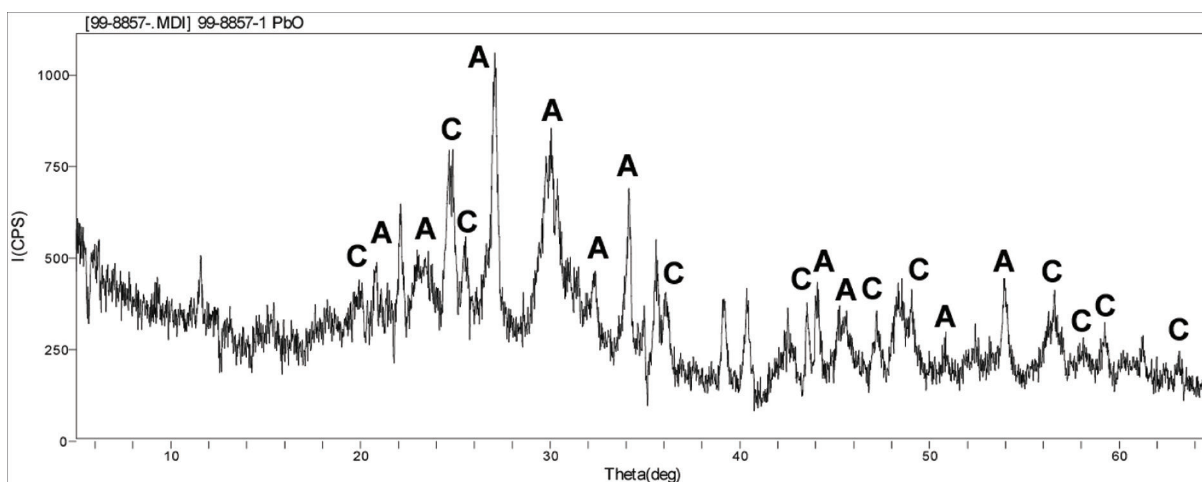

**L**. "Ochre" fragment H2000/9999-122, (G = Goethite peak).



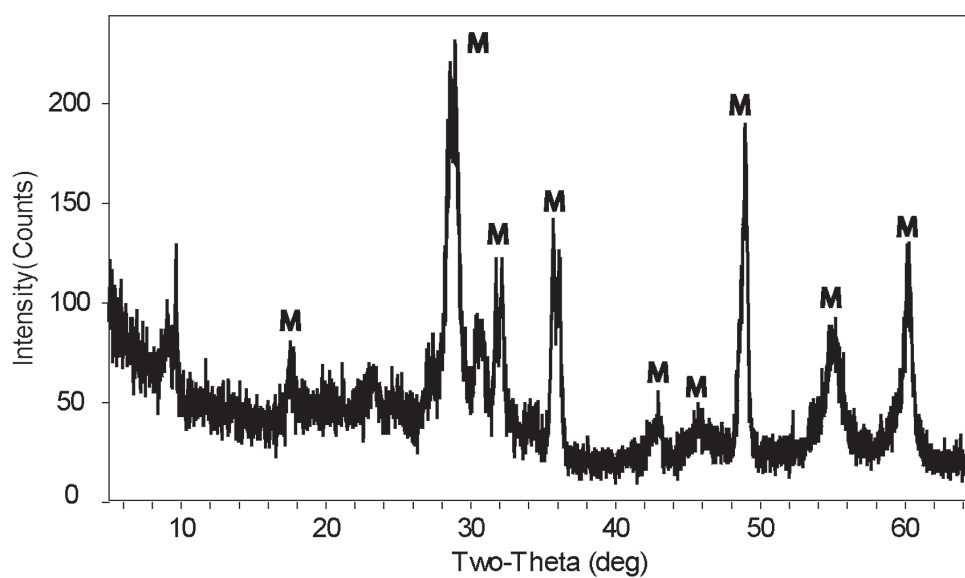
**M**. Lead ore fragment H90/3011-147, (G = Galena peak, A = Stibnite (Antimony peak).



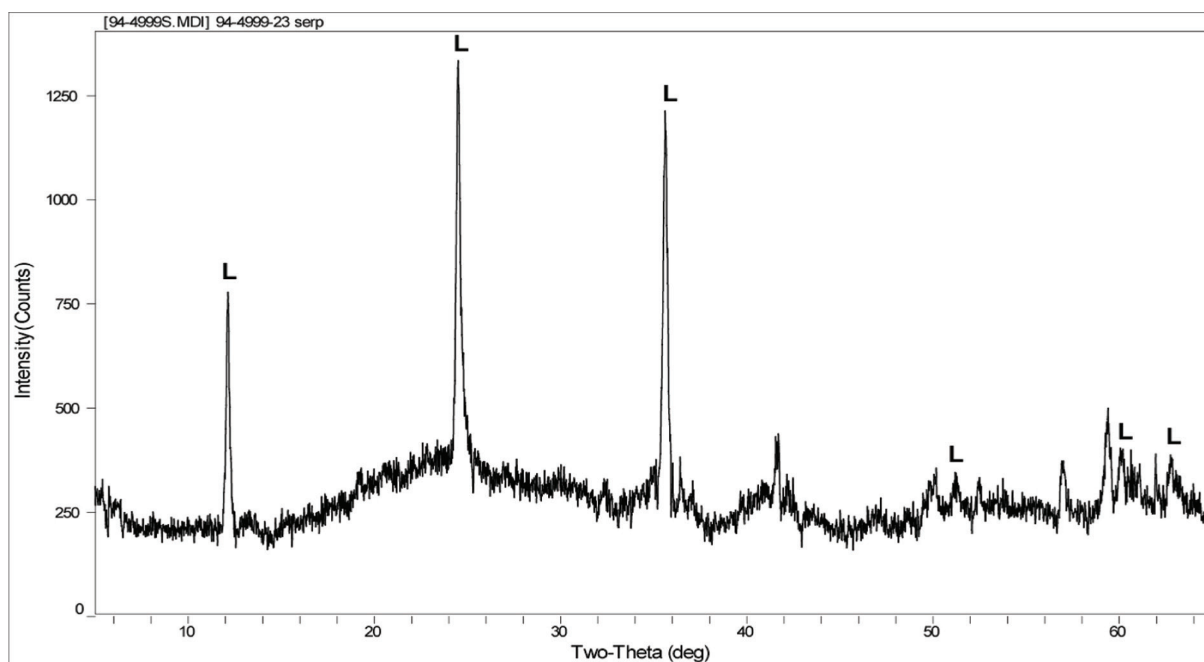

**N**. Lead ore fragment H99/8857-1, (C = Cerussite peak, A = Anglesite peak).



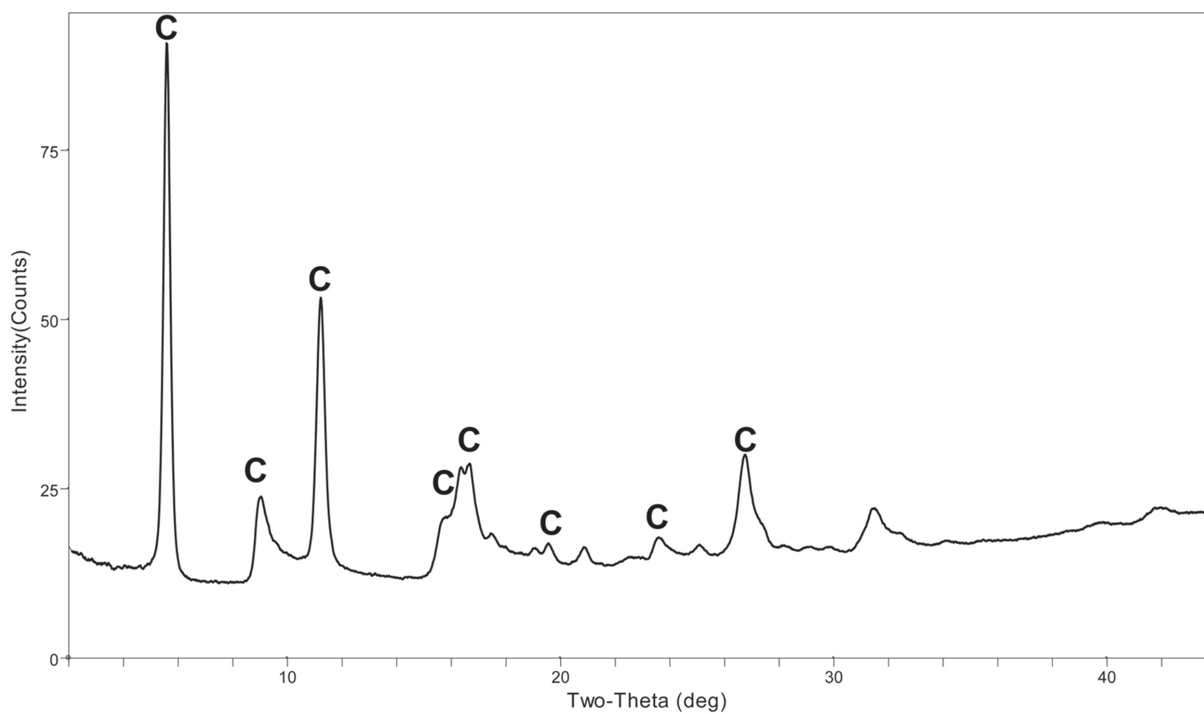

**O**. Lead ore fragment H90/3193-6, (M = Massicot peak).



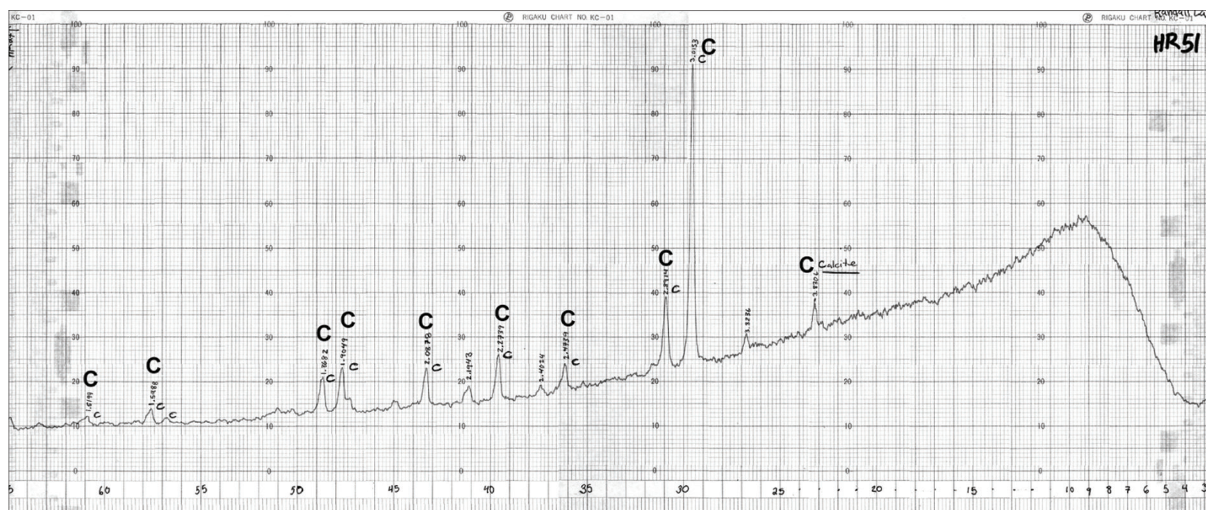
**P**. Serpentine fragment H94/4999-23, (L = Lizardite peak).



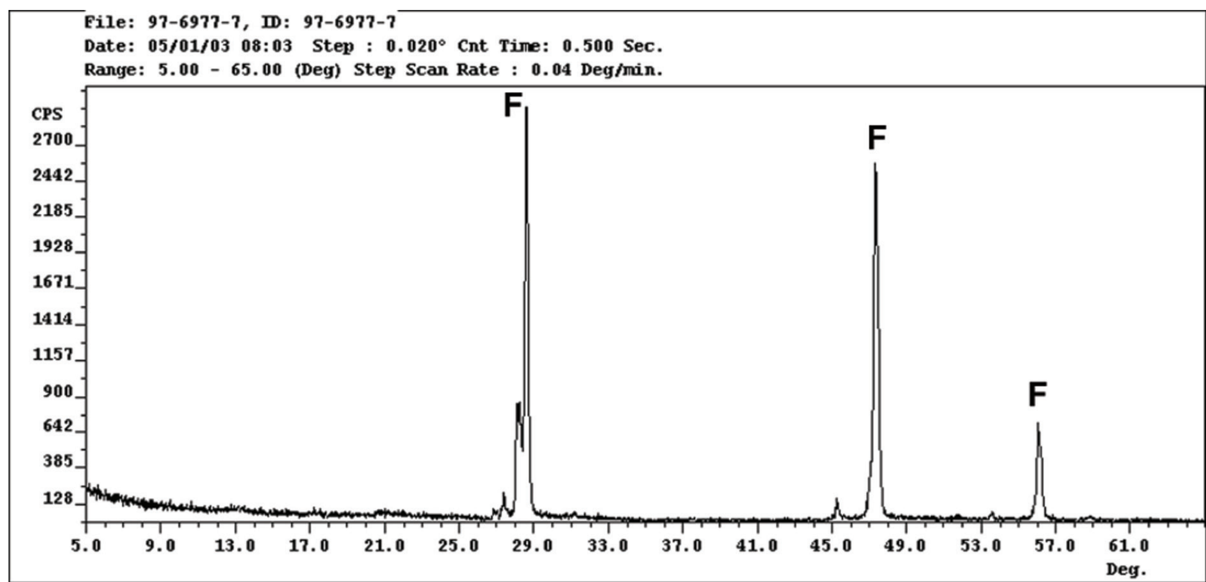

**Q**. Serpentine bead H2000/9508-2, (C = Clinochrysotile peak).



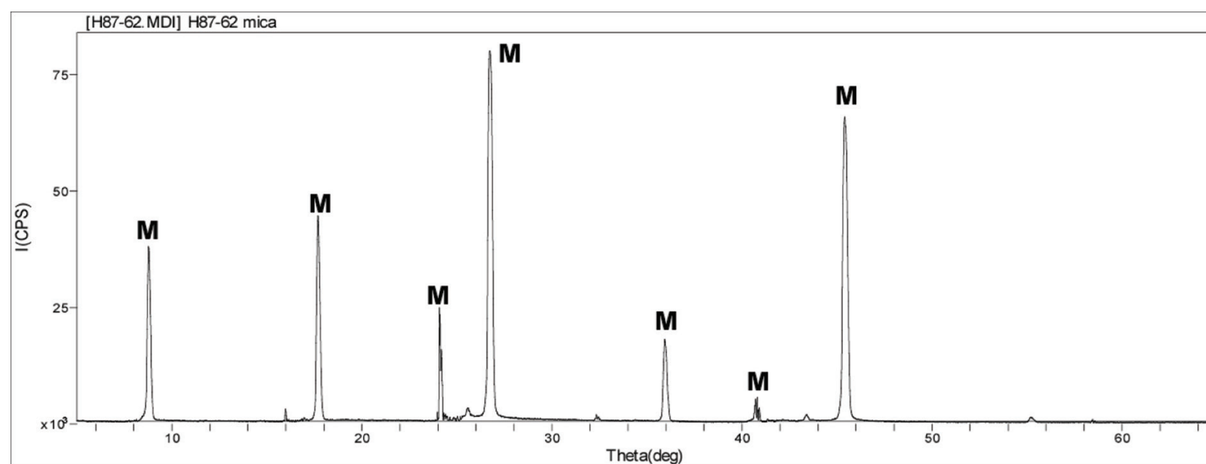
**R**. Calcite fragment H2000/2110-77, (C = Calcite peak).



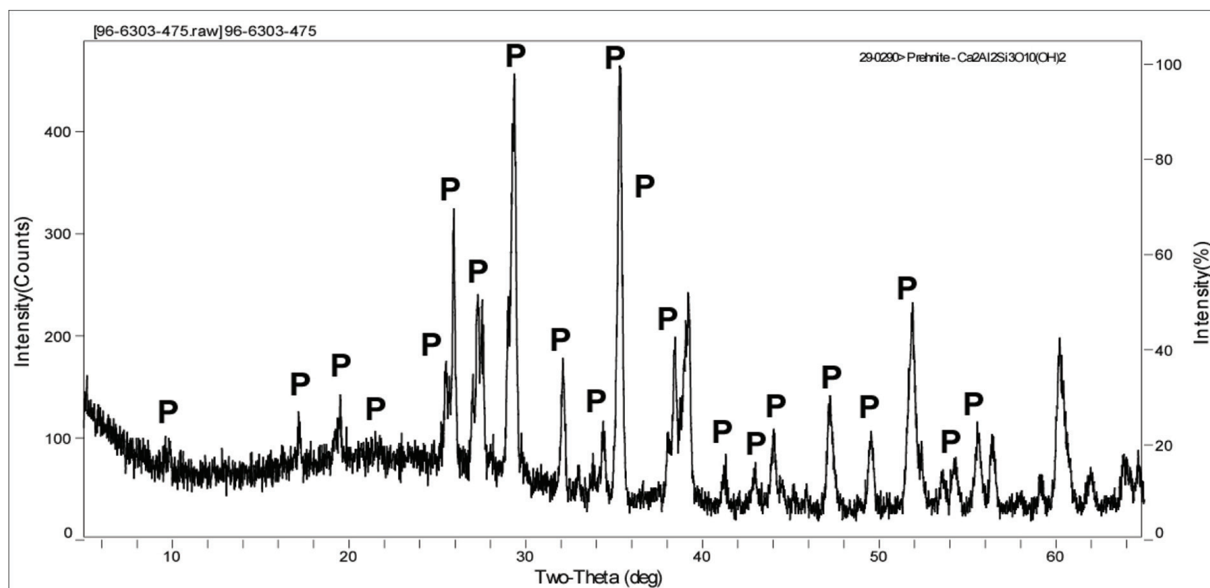

**S**. Fluorite fragment H97/6977-7, (F = Fluorite peak).



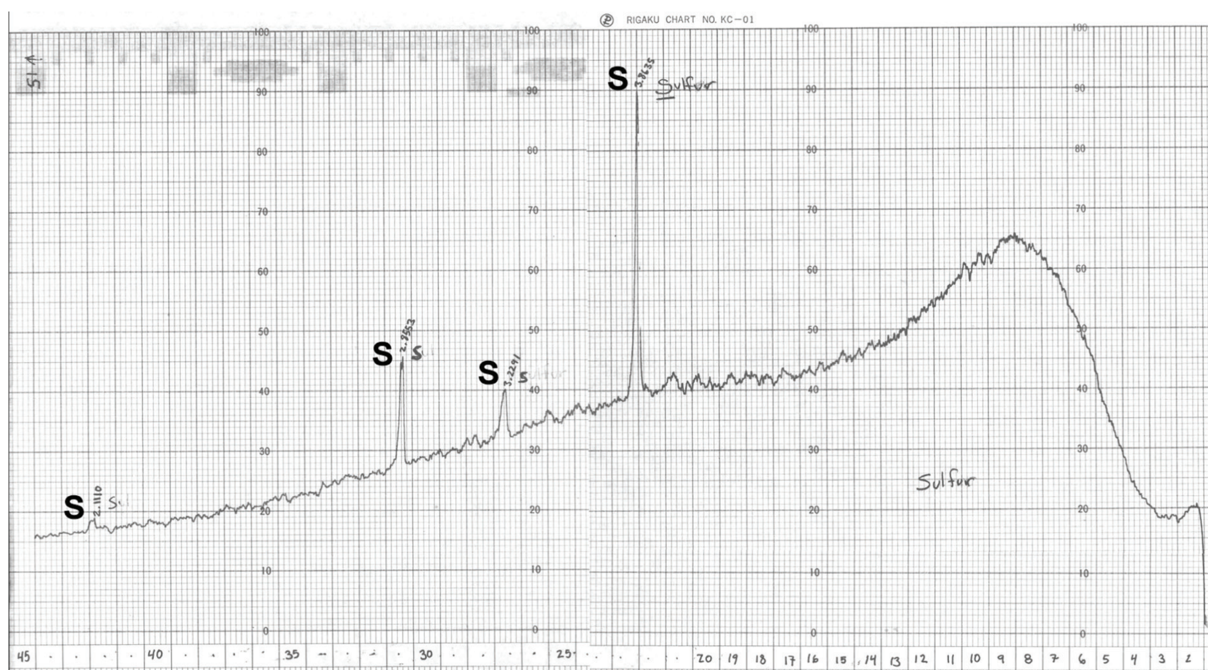

**T**. Mica fragment H87/62, (M = Muscovite peak).



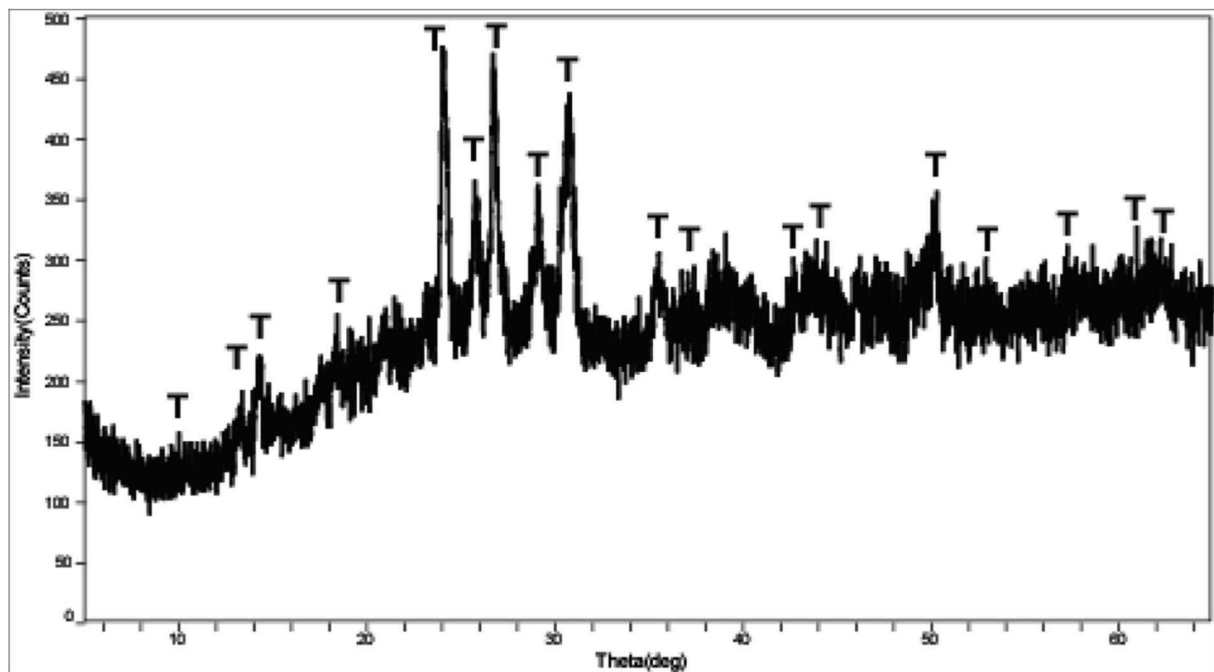
**U**. Prehnite fragment H96/6303-475, (P = Prehnite peak).



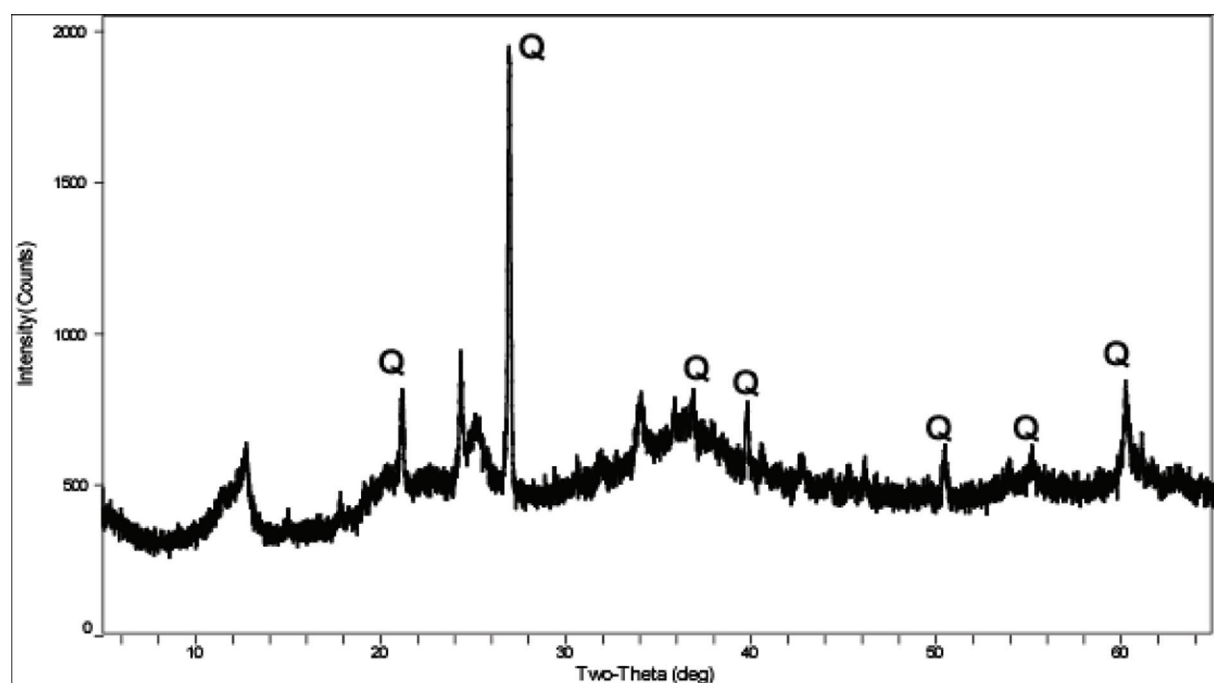

**V**. Sulfur fragment H96/6219-43, (S = Sulfur peak).



**W**. Turquoise fragment H94/4999-213, (T = Turquoise peak).




**X**. Chagai "turquoise" sample from J.-F. Jarrige, (Q = Quartz peak).



# APPENDIX 4.3

## CHARACTERIZATION OF TWO BASALT ARTIFACTS USING EMPA

Basalt is a dense, dark-colored volcanic rock that is composed mainly of plagioclase and pyroxene minerals, but which may sometimes contain significant amounts of olivine (Lapidus and Winstanley 1990: 53). By using EMPA to study the chemical compositions of clinopyroxene crystals in samples, geologists can often identify the tectonic settings (continental, island arc, ocean floor) in which rocks of this kind most probably formed (LeBas 1962; Nisbet and Pearce 1977). Leanne Mallory-Greenough and others (1998) successfully employed this method to characterize and determine the regional geologic provenience of minute pieces of basalt temper in an Egyptian potsherd. Two fragments of basalt recovered from surface contexts at Harappa were selected for exploratory EMPA (Appendix 4.3 Figure 1) to see if similar results could be achieved for artifacts from an Indus Civilization site. Both artifacts were examined using the electron microprobe's back-scatter electron (BSE) imaging and wavelength dispersive spectrometry (WDS) features.

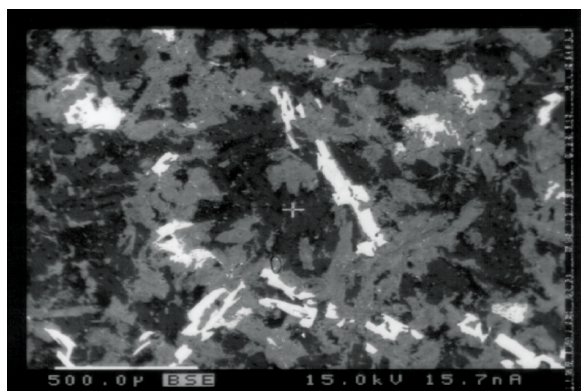
The first artifact examined – H2000/9999-127 (pictured in the third image of Figure 4.4 B), is a large basalt flake that appears to have broken from a pestle or rubbing-stone. The BSE image (Appendix 4.3 Figure 1 A) shows that pyroxene minerals (gray phases) partially surround lathe-like plagioclase crystals (lightest phases), giving the stone a slightly *sub-ophitic* texture (Shelley 1993: Figure 1.17a) that is somewhat reminiscent of *dolerite* (the intrusive equivalent to basalt). WDS scans were made on clinopyroxene crystals at 16 different points extending across the sample. The second artifact examined – H2000/9999-128 (not pictured), is a small, non-diagnostic chunk of basalt. Its BSE image (Appendix 4.3 Figure 1B) revealed a much finer, inter-granular texture than that of the first example, one that is quite typical of basalts (ibid.: Figure 1.31b). For this sample, WDS scans were made on 15 different clinopyroxene crystals. Eight oxides were measured and the results of all scans were averaged for each artifact. These data are reported in Appendix 4.3 Figure 1 C.

One way that geologists classify igneous rocks like basalt is according their *alkalinity* – a term which, in this instance, refers to the relative abundance of silica to sodium or potassium- rich minerals in a sample (McBirney 2007: 38-45). The silica and aluminum composition of clinopyroxene crystals in a basalt sample has been shown to be indicative of the alkalinity of the magma from which it formed (LeBas 1962). Using the averages of their measured $SiO_2$ and $Al_2O_3$ abundances, the Harappan artifacts are plotted on Appendix 4.3 Figure 1 D in relation to dashed lines that demarcate the approximate boundaries between sub-alkaline, alkaline and peralkaline volcanic rocks (ibid.). Both fall clearly into the *sub-alkaline* category. Basalts of this kind are the most common rocks in oceanic crust (Lapidus and Winstanley 1990: 510) and so the artifacts might very well have originated in one of the ophiolite sequences (obducted oceanic crust) found intermittently to the north and west of the Indus Basin. However, sub-alkaline basalts are known to sometimes occur in volcanic formations associated with continental and island-arc settings.

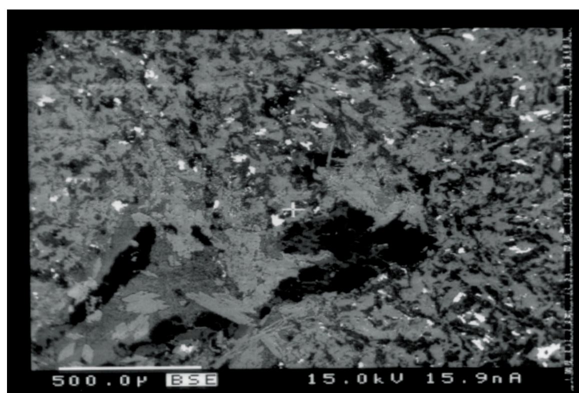
Using canonical discriminant analysis and data on the same eight oxides measured here, Nisbet and Pearce (1977) compared a large set (n = 329) of volcanic rocks from four different geologic settings: OFB – ocean floor basalts; VAB – volcanic arc (or active continental margin) basalts; WPT – within-plate (continental) tholeiitic basalts; and WPA – within-plate alkali basalts. Reasonably good

**Appendix 4.3 Figure 1** EMPA characterization of two basalt fragments from Harappa.

**A.** BSE image of H2000/9999-127.



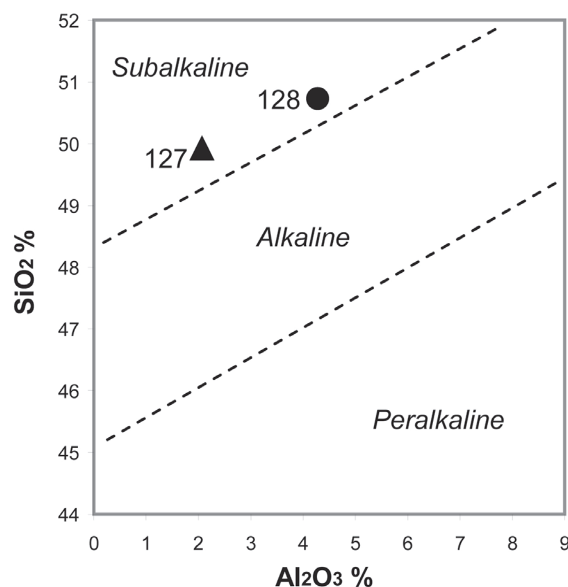

B. BSE image of H2000/9999-128.



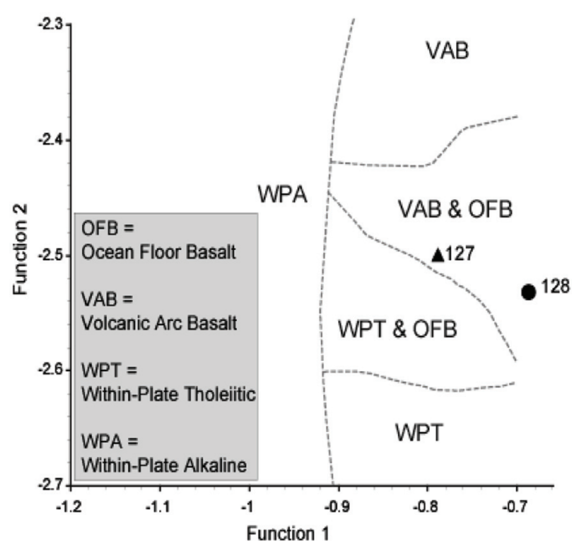

**C.** Composition of clinopyroxene of crystals in the two basalt fragments.

| | H2000/9999-127 (average of 16 analysis points) | H2000/9999-128 (average of 15 analysis points) |
|---|---|---|
| $Al_2O_3$ | 2.07 | 4.28 |
| $CaO_2$ | 14.56 | 11.04 |
| $FeO_2$ | 17.63 | 14.19 |
| $MgO_2$ | 13.02 | 14.82 |
| $MnO_2$ | 0.43 | 0.26 |
| $Na_2O$ | 0.26 | 0.44 |
| $SiO_2$ | 49.92 | 50.73 |
| $TiO_2$ | 0.87 | 0.30 |
| totals | 98.80 | 96.23 |

**D.** Silica/alumina plot of Harappan basalt fragments clinopyroxenes compositions (boundaries after LeBas 1962).




**E.** Harappan basalt artifact clinopyroxene composition data plotted in relation to basalts from different tectonic settings. (Functions and boundaries after Nisbet and Pearce 1977)



separation between the four grouped sub-sets was achieved (the average correct classification success rate was around 70%) and, using the first and second discriminant functions, they created a visual plot with boundaries roughly demarking the zones where samples from the various geologic settings fell (ibid.: 153). Mallory-Greenough and others used a version of this plot (1998: Figure 6) in their effort to identify the geologic provenience of basalt temper fragments. I have created another version (Appendix 4.3 Figure 1 E) upon which the two Harappan basalt artifacts are plotted using the discriminant functions published by Nisbet and Pearce (1977: 152). Both samples fall within the combined VAB and OFB zone.

This preliminary study indicates that the two fragments of dark-colored stone examined here are sub-alkaline basalts that likely came from volcanic formations associated with either oceanic crust (ophiolites) or subduction zones (at island arcs or active continental margins). Although this leaves open a wide range of potential geologic sources around northwestern South Asia (most of them on the northern and western margins of the Greater Indus Valley region), it is possible to state, with reasonable confidence, that these artifacts are probably *not* related to the continental flood basalts of peninsular India and Gujarat known as the Deccan Traps. Whole rock analysis (Mallory-Greenough and Greenough 2004) and potassium-argon dating (Weinstein-Evron *et al*. 1995) have shown promise in helping to more narrowly define the probable regional provenience of basalt artifacts and may eventually be employed in future studies on these and other objects made of that stone from Harappa.

# APPENDIX 4.4

# THE LAPIS LAZULI QUESTION

## INTRODUCTION

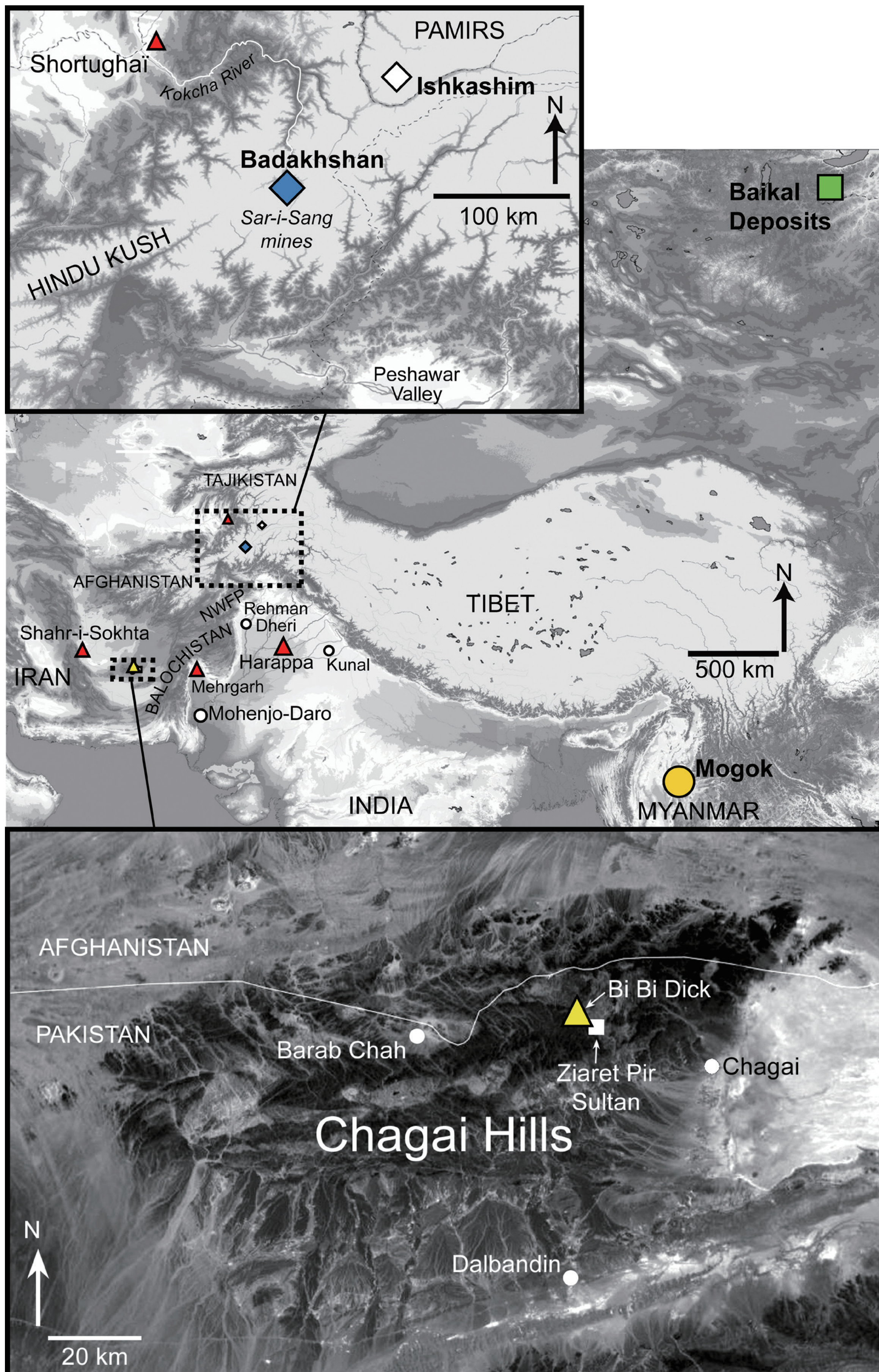
"Where did the lapis lazuli come from?" This was the first question that the late Prof. Farzand Durrani asked me at a gathering at the University of Peshawar back in 2000. He, of course, knew of Georgina Herrmann's seminal study (1968) in which she had evaluated all of the reported sources of lapis lazuli in the Old World and concluded that deposits in northern Afghanistan's Badakhshan Province were almost certainly the only ones exploited in ancient times. He had assumed the raw stone for the hundreds of lapis lazuli artifacts he had excavated at the Early Harappan settlement of Rehman Dheri on Pakistan's Gomal Plain (Durrani *et al.* 1995) originated in that region, around 475 km due north of the site. In recent years, however, there had been reports of another potential source in the Chagai Hills of western Balochistan Province, Pakistan. Prof. Durrani was, therefore, quite interested to learn if this "new" source, which was said to be located some 675 km to the west-southwest of Rehman Dheri, was genuine. I did not have a satisfactory answer for him at the time. I said that I too had heard of this supposed source but was having a difficult time finding any detailed information on it at all. I told him that I would work on the question.

Now 10 years later, I have reached the same conclusion that Georgina Herrmann did four decades ago – deposits in the Badakhshan region of northern Afghanistan would have been the *only* viable sources of lapis lazuli for peoples in ancient northwestern South Asia or their contemporaries in the Near East. It is highly improbable that this important luxury material occurs in the Chagai Hills. Examples of lapis lazuli that have been attributed to that area were, in all likelihood, actually derived from the Badakhshan deposits. In this appendix, I discuss the research and analyses that have led me to these conclusions. Appendix 4.4 Figure 1 is a map with insets that shows the regions, lapis lazuli sources (both genuine and questionable) and sites that are mentioned in this discussion.

## LAPIS LAZULI IN ANCIENT SOUTH ASIA

The earliest evidence for the use of lapis lazuli in South Asia (or anywhere else) comes from Mehrgarh, where a few small beads were unearthed in burials dating to the seventh millennium BC (Jarrige 1991b: 41). By the time Harappa was founded, roughly three thousand years later, this stone was being transported through exchange networks that brought it to sites across Balochistan (Besenval 2000: 170; Hargreaves 1929: 33-34; Tosi and Vidale 1990), the NWFP (Khan *et al.* 1991a: 58-59) and into Cholistan (Dogar 2001: 11). Finished lapis lazuli objects and debris fragments from early Ravi Phase strata at Harappa indicate that the fourth millennium BC residents of that site on the Punjab Plain were also participants in those exchange networks and acquired at least some of that stone in raw form.

Lapis lazuli was traded over an even wider area of northwestern South Asia during the Harappan Period (for information on sites where it has been found see Asthana 1993: 271-273; Chakrabarti 1978; Lahiri 1992; and Ratnagar 2004: 185-193). However, artifacts made from this material tend not to be found in great abundance at those sites where they are present (a few notable exceptions are mentioned below). Case in




**Appendix 4.4 Figure 1** Archaeological sites and lapis lazuli sources discussed in this appendix.

**Appendix 4.4 Figure 2** Spatial and temporal distribution of lapis lazuli artifacts at Harappa.

| Context | *fragments, manufacturing debris and unfinished beads* | *finished beads, pendants or ring* |
|---|---|---|
| **Period 1** | 3(AB) | 1(AB) |
| **Period 2** | 1(E) | 6(AB) 4(E) |
| **Period 3A** | ø | 21(AB) 3(E) |
| **Period 3B** | ø | 4(E) 1(ET) 1(cemetery) |
| **Period 3C** | 2(E) 1(cemetery) 5(ET) 1(F) | 8(AB) 7(E) 2(ET) 1(cemetery) 5(F) |
| **Period 4/5** | ø | 2 (AB) |
| **surface & disturbed deposits** | 5(AB) 12(E) 5(ET) 3(F) 12(other) | 30(AB) 16(E) 2(ET) 2(F) 8(other) |
| ***total*** | **50** | **124** |

point – Mohenjo-daro, which was located at the nexus of long-distance trade routes and was home to a large population of affluent elites who, presumably, sought to differentiate themselves through the consumption of exotic materials. Only a pitiful few (perhaps less than a dozen in total) lapis lazuli artifacts have been recovered at this, the largest Indus city (Mackay 1931c: 525; Mackay 1938: 499; Pracchia *et al*. 1985: 236; Bondioli *et al*. 1984: 24). Because of its apparent limited use there and at most other Indus Civilization sites, the stone is often thought of as being a material that, for various reasons (discussed by Shaffer 1982: 193; Kenoyer 1998: 96; Vidale 1989b: 180), was "never as highly esteemed in India as in ancient Egypt or Mesopotamia" (Buddruss 1980: 26). Such assessments are probably fair. The tremendous value that some ancient Near Eastern societies placed on lapis lazuli during the fourth and third millenniums BC and the large amounts of that material they consumed is clearly evident in the textual and archaeological records of that region (von Rosen 1988, 1990). The high demand for this stone in Mesopotamia seems to have been an important stimulus for trade across the Iranian plateau during that time (Sarianidi 1971; Tosi 1974a) and a key aspect of the economies of certain settlements located in that region – most notably Shahr-i-Sokhta, a Helmand Tradition site where large quantities of lapis lazuli were evidently prepared for export (Tosi 1974a: 15).

The utilization of lapis lazuli by Indus Civilization peoples was, in comparison to their contemporaries to the west, undeniably less intense. Even so, I am hesitant to believe that it was an unimportant or even a particularly rare material during the Harappan Period (although its greatly limited use at a settlement as large and centrally located as Mohenjo-daro is problematic) simply because it is found across such a wide area and, at a few sites at least, it was rather abundant. The 104 debris fragments found in Harappan levels at Shortughaï in northern Afghanistan (Francfort 1989: 145, 173) appear to indicate that, during the Harappan Period at least, Indus peoples had direct access to (some have suggested even controlled - see Asthana 1993: 273; Ratnagar 2004: 189) a major source of that material located in the nearby Badakhshan region (discussed below). Nearly 500 lapis lazuli beads and fragments were recovered at Rehman Dheri (Durrani *et al*. 1995a) and more than 5500 were part of a single large cache at Kunal in Haryana (Khatri and Acharya 1997: 86). I have recently recorded 125 beads made from this stone and several debris fragments (two of which were confirmed using XRD to be lazurite) among excavated materials from the site of Dholavira in

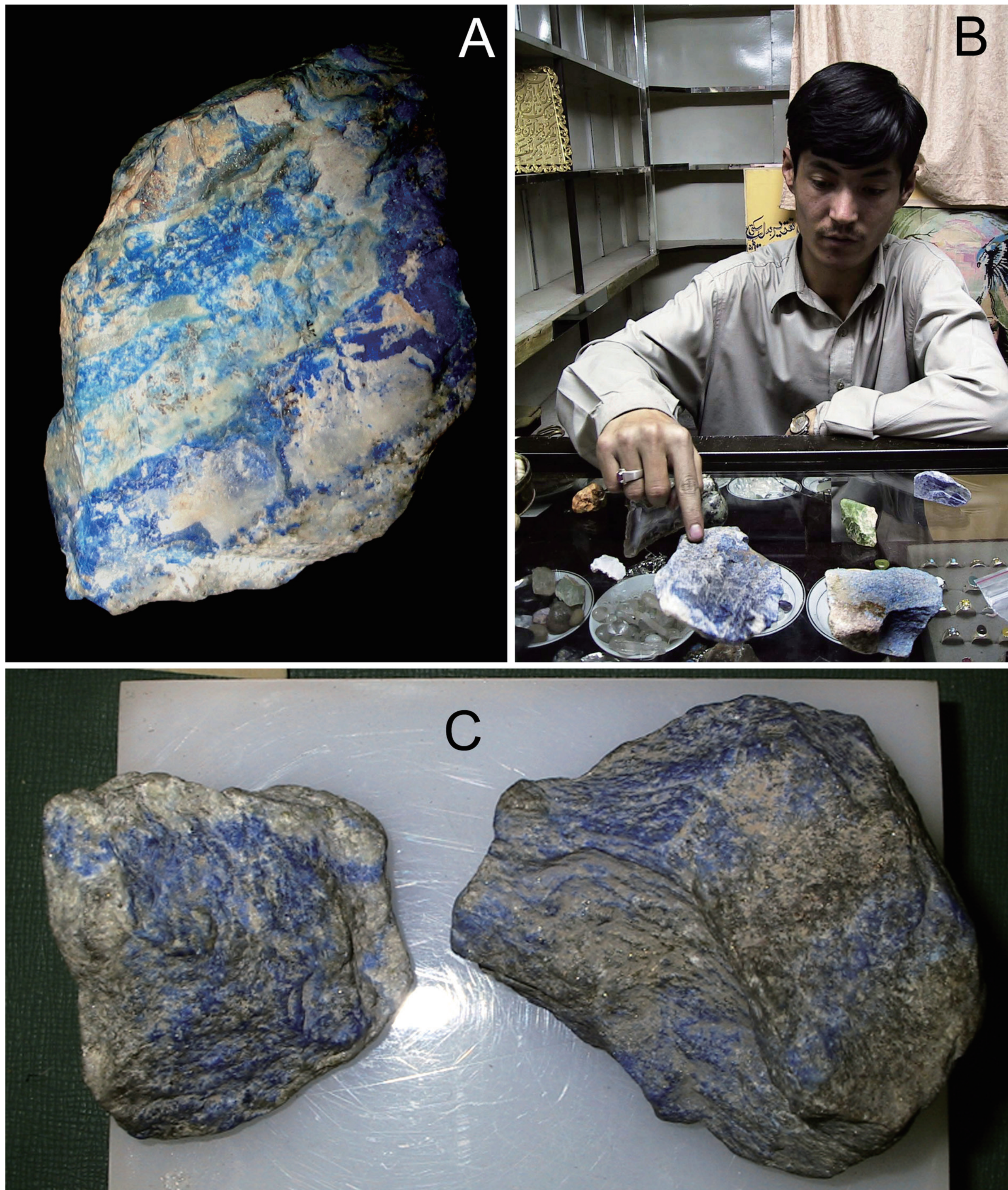
Gujarat. At Harappa, lapis lazuli artifacts have been recovered from every one of the site's chronological phases and sub-phases (Appendix 4.4 Figure 2). The largest sub-assemblage dates to Period 3C, from which 23 finished objects and nine debris fragments have been recovered. That lapis lazuli was, in general, used sparingly by Indus Civilization peoples is less important in terms of the current study than the fact that Harappans appear to have had good access to it and that it was present at many sites. Identifying the potential geologic source(s) of such a widely used stone is the main concern here.

## POTENTIAL HARAPPAN LAPIS LAZULI SOURCES

*Lazurite* – the constituent of lapis lazuli that gives the rock its blue color – is a rare mineral in nature (Hogarth and Griffen 1976b: 2). Where it is found, it typically occurs as specks, masses and, occasionally, crystals in zones of marble formed where impure limestone was metasomatized by intrusive granitic rocks (Deer *et al*. 1992: 502). The only *well-documented* lazurite/lapis lazuli sources in Asia are: the Sar-i-Sang area deposits in the Badakhshan District, Afghanistan (Bowersox and Chamberlin 1995: Chapter 3; Faryad 2002; Kulke 1974; Herrmann 1968: 22-27; Wyart *et al*. 1981; Yurgenson and Sukharev 1985); a very small occurrence in the Ishkashim region of the Pamir Mountains, Tajikistan (Ivanov and Sapozhnikov 1985: 14-18; Lutniski 1955; Ostroumov *et al*. 2002; Sapozhnikov 1992); and a series of deposits in Siberia southwest of Lake Baikal (Bauer 1904: 442-444; Hogarth 1970; Ivanov 1976; Ivanov and Sapozhnikov 1985: 5-14; Ostwald 1963). By well-documented I mean that there are published photographs of the deposits, maps and precise geographic coordinates, descriptions of mining areas and of mining activities, geologic section drawings, studies of the host rocks and numerous mineralogical analyses of lapis lazuli samples from those locations. There is not a shred of doubt that these occurrences actually exist. Deposits said to be located in the Ural Mountains of Russia and the Mogok area of Myanmar (Bender 1983: 208; Brown and Judd 1896: 213; da Cunha 1989: 69-70), although poorly documented, are likely genuine given the suitable geology of those regions and the analysis of samples said to be from those source areas that seem to be geochemically distinctive (see the sulfur isotope analysis below as well as Casanova 1992 and Zöldföldi *et al*. 2006). Various older reports and rumors of lapis lazuli occurrences in India, Iran and Egypt are, however, almost certainly spurious (Aston *et al*. 2000: 39; Herrmann 1968: 27; Irvine 1841: 162; Karanth 2000: 209). Just over two decades ago, a deposit supposedly located in the Chagai Hills of western Balochistan, Pakistan was first brought to the attention of scholars (Jarrige 1988: 28). It is now frequently cited as a potential source for the lapis lazuli used in antiquity (Kenoyer 1998: 96; Lahiri 1992: 22; Possehl 1999: 236; Ratnagar 2004: 185) and samples purported to be from there have even been used in recent geologic provenience studies of artifacts (Casanova 1997) and pigments (Ballirano and Maras 2006) made from that stone. An occurrence in western Balochistan would, *if genuine*, have tremendous implications for studies of trade and interaction between the ancient peoples of the Indus region, eastern Iran and southern Afghanistan. However, there are many reasons to doubt that lapis lazuli actually exists in the Chagai Hills.

## DOUBTS ABOUT A SOURCE OF LAPIS LAZULI IN THE CHAGAI HILLS

The first direct mention of lapis lazuli in the Chagai Hills of which I am aware[1] are those relating to explorations in the region during the mid-




**Appendix 4.4, Figure 3** Lapis lazuli purported to be from the Chagai Hills, Balochistan. **[A]** Sample of "Chagai Hills" lapis lazuli given to Jean-François Jarrige by Usman Hassan. **[B]** "Chagai Hills" lapis lazuli for sale at Abdul Karim's rock shop, Liaqat Bazaar, Quetta, Balochistan. **[C]** Lapis lazuli samples in the GSP-Quetta Museum labeled "Brab Chah, Chagai."

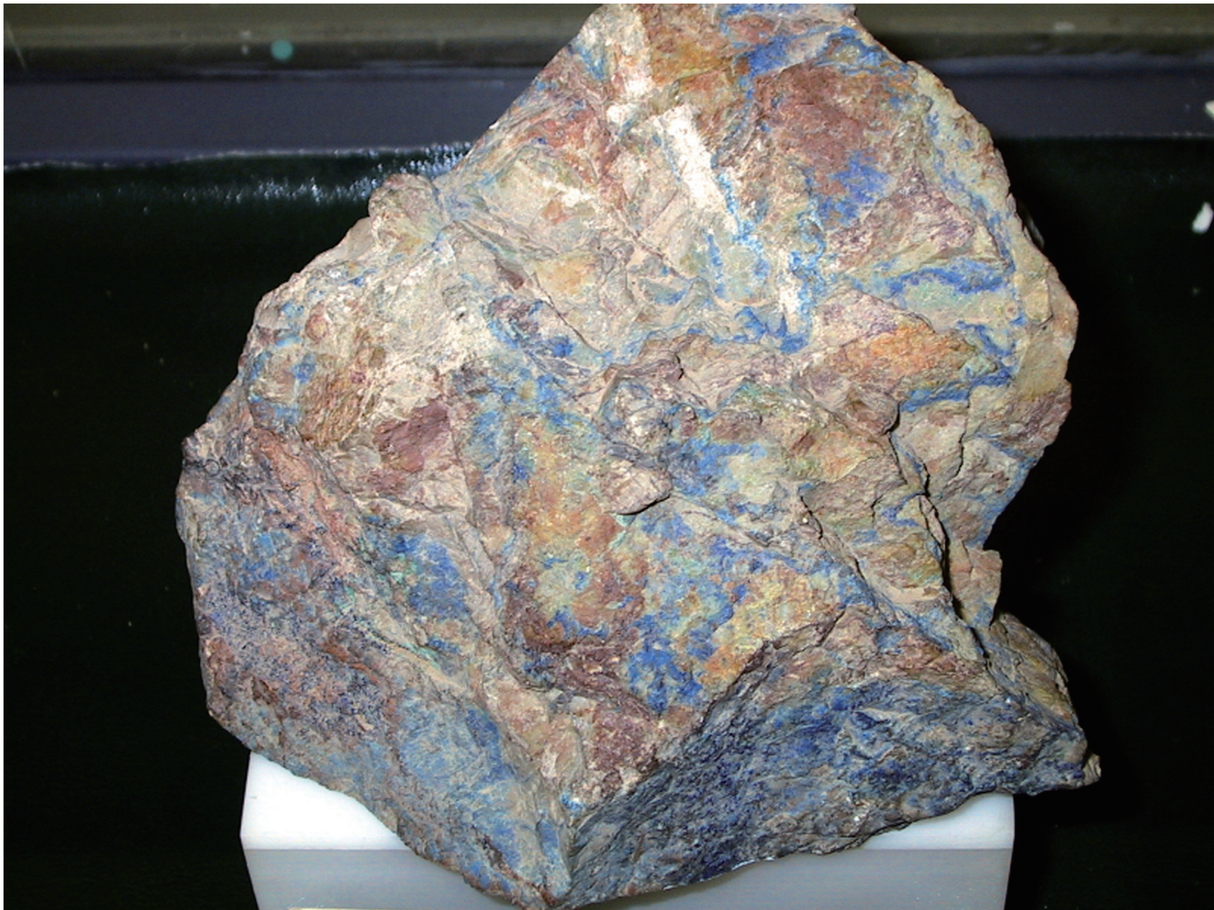
1980s by Jean-François Jarrige, leader of the French Archaeological Mission to Pakistan, and Usman Hassan, a now deceased Pakistani ex-military officer who was a friend of Jarrige's and who had a keen interest in archaeology (Jarrige 1988: 28; Jarrige and Hassan 1989: 160-162). The deposit they reported is said to exist at a location called Bi Bi Dick, approximately 56 km north of Dalbandin, near the Pakistan-Afghanistan border. Jarrige himself never actually visited the location (Jean-François Jarrige

*personal communication* 2003) but somehow Hassan obtained samples said to be from there, some of which he gave to Jarrige (Appendix 4.4, Figure 3 A). Those samples were analyzed by the Geological Survey of Pakistan and confirmed to be genuine lapis lazuli (Khan *et al*. 1985). Whether or not Hassan himself actually visited the supposed source to collect the samples is unclear. Jarrige believes that he may have but no account of the source/mine was ever given such as the one Hassan published about old lead workings in the Khuzdar District (Hassan 1989). Nor is there any mention of it be found in Hassan's posthumously published collection of observations on the archaeology and history of Balochistan (Hassan 2002).

I have conducted exhaustive searches of the geologic literature relating the Chagai Hills but, to date, have found no reference to either lazurite or lapis lazuli in that region. I have spoken with numerous geologists at the Geological Survey of Pakistan (GSP), at the University of Balochistan-Quetta, and several working for private firms operating in the Chagai Hills region about the possibility of lapis lazuli being found there but most had never even heard of such an occurrence. The few that had seriously doubted that it actually existed. Nearly everyone questioned if it were even geologically possible for lapis lazuli to form in the Chagai Hills, which are mostly composed of andesitic volcanic rocks (Bannert 1995: 19). Lazurite forms in metamorphosed limestones and then only under exceptional conditions (thus its rarity). Rich polymetallic (copper, lead, zinc, molybenite and gold) ores occur in and to the west of the Chagai Hills and, because of that, the region is one of the better surveyed and mapped parts of Balochistan (Allan Spector and Associates Ltd. 1981; Dykstra and Birnie 1979; Hunting Survey Corporation 1960; Nagell 1975; Taghizadeh 1974; Vredenburg 1901). However, there is no mention of lazurite or lapis lazuli in any of the geologic literature related to that region. I consulted the published GSP map that covers the area around Bi Bi Dick (Ziaret Pir Sultan quad sheet 34 C/7) where the source is said to be located and others covering adjacent areas (Barab Chah quad sheet 34 C/3 and Chagai quad sheet 34 C/11). Metamorphic rocks are not found there. Plainly stated, lapis lazuli should not occur in the Chagai Hills given what is known about the geology of the region. The samples attributed to a source near Bi Bi Dick that Usman Hassan had analyzed by the GSP were most definitely genuine lapis lazuli, however. How could Hassan have obtained that stone from the Chagai Hills if it were geologically unlikely for it to occur there? Dr. Wazir Khan of the GSP-Quetta offered a possible explanation (*personal communication* 2001). He related that a tremendous amount of narcotics smuggling and other clandestine trade took place across the Pakistan-Afghanistan border in western Balochistan, particularly through the rugged Chagai Hills region. Marble, travertine and other types of stone are frequently brought to Quetta from Afghanistan and, rather than having to pay duty on imported goods, those transporting the stone attribute it to sources in the Chagai District. Lapis lazuli from "Chagai" can be found in the bazaars of Quetta, I have even purchased some (Appendix 4.4 Figure 3 B). Dr. Khan suggested that Hassan's samples may have been some of this smuggled material.

Confusing matters further, there are two samples of lapis lazuli in the museum at the GSP headquarters in Quetta (Appendix 4.4 Figure 3 C) that are labeled "Brab Chah, Chagai" I questioned the curator of the museum and other members of the Survey about these samples and learned that they were donated by a former GSP administrator. I was told that this person (who I will not name here) did not do fieldwork in the Chagai Hills and, in fact, was never known to have travelled west of Quetta. They said it is highly

1) There are reports of lapis lazuli in the Balochistan region going back to the 1800s (see Ball *et al*. 1881: 529) but none specifically identify the Chagai Hills region.



**Appendix 4.4 Figure 4** Azurite (hydrated copper carbonate) sample from Koh-i-Dalil, Chagai District, Balochistan that is very lazurite-like in appearance.

unlikely that the former administrator collected the samples personally and, thus, their provenance is, like other examples of "Chagai Hills" lapis lazuli, questionable.

The story does not end there. In the 1990s, Michèle Casanova used atomic absorption spectrometry to compare lapis lazuli artifacts from proto-historic sites in Iran (Shahr-i-Sokhta and Tépé Sialk) to geologic samples from several sources in Asia including eleven purported to be from the Chagai Hills (Casanova 1992, 1997; Delmas and Casanova 1990). More recently, Ballirano and Maras (2006) used Raman spectroscopy to compare a sample of *ultramarine* (a blue pigment made from powdered lazurite) from Michelangelo's fresco "The Last Judgment" to small sets of lapis lazuli samples from Sar-i-Sang (n=3) and the supposed Chagai Hills source (n=5). These researchers obtained the "Chagai Hills" samples that they analyzed from Prof. Maurizio Tosi who was in possession of a collection of lapis lazuli, supposedly from that region, given to him in the 1980s by Emmanuel Lizioli – an Italian living in Pakistan who had business investments in the onyx marble (variegated calcite) quarries of the western Chagai District (Maurizio Tosi *personal communication* 2005). Sadly, like Usman Hassan, Mr. Lizioli is no longer living and he left no record of how he obtained the samples. For this reason, the provenance of the "Chagai Hills" lapis lazuli samples analyzed in these recent studies should be considered very uncertain.

In 1984, Prof. Tosi visited the Chagai Hills region and attempted to reach the lapis lazuli "source" reported there. Although he was unsuccessful due to the troubled nature of the area, the local inhabitants that he spoke with at the village of Barab Chah near

the Afghanistan border "were quite plain in declaring that blue stone" could be found in the area (Maurizio Tosi *personal communication* 2006). There is no particular reason to doubt that those locals were being anything other than truthful with Prof. Tosi and I am quite sure that they believed the "blue stone" they told him of to be *lazhward* (لاژورد – the Persian word for lapis lazuli that is also used in the various languages spoken in Pakistan). However, through my own personal experience I have come to realize that many people (even some jewellers) are apt to call any variety of bluish-colored rock "lazhward." The "blue stone" that the people at Barab Chah were referring to was, in all probability, *azurite* – a hydrated copper carbonate. As pointed out above, copper mineralization occurs throughout the Chagai Hills region. Geologists that do fieldwork there have shown me samples (Appendix 4.4 Figure 4) and photographs of zones of brilliant blue azurite and apple-green chrysocolla (*personal communication* – Abdul Razique and Razzaq Abdul-Manan of Tethyan Copper Limited and the Center of Excellence in Mineralogy, University of Balochistan-Quetta). Those copper minerals can easily be (and frequently are) mistaken for semi-precious stones like lapis lazuli and turquoise and are sometimes even used as simulants for them (da Cuhna 1989: 116-17). The same geologists also told me that old pits where azurite and malachite have been extracted in the past can be found at a place called Ziaret Pir Sultan, which just so happens to be located within a few kilometers of the supposed lapis lazuli source at Bi Bi Dick. It is quite probable that accounts of a "lazhward" source in this part of the Chagai Hills actually refer to old those workings or ones like them. Rumors of an occurrence there would have no doubt gained credence when genuine lapis lazuli smuggled from Afghanistan ended up in the bazaars of Quetta and was attributed to this region. Although that is how it may have happened, it is impossible to know for certain. In any case, the existence of lapis lazuli in the Chagai Hills region remains unconfirmed and, geologically speaking, highly unlikely if not impossible.

Michèle Casanova's provenience study of lapis lazuli artifacts, although groundbreaking, produced results that were largely inconclusive. The artifacts she analyzed from Shahr-i-Sokhta variously appeared to be related to samples from northern Afghanistan, Tajikistan and the "Chagai Hills" (Casanova 1992: 56). While it is conceivable that material from multiple deposits might be found at that site, the actual assignment of the artifacts to sources was simply not convincing. The same can be said of the study of ultramarine from "The Last Judgment," which produced results that Ballirano and Maras themselves described (2006: 997) as "dubious." My reservations about accepting the provenience determinations made in these two studies lie not with the researchers' methods but with their datasets. The first and most obvious weakness is the great uncertainty surrounding the origins of "Chagai Hills" lapis lazuli samples. It seems highly probable that those particular samples were derived from one of the Badakhshan region deposits in northern Afghanistan and came into Lizioli's possession (and eventually Tosi's) via business associates or other contacts in the Chagai District. Although it is true that in both studies there were some geochemical differences between the "Chagai Hills" samples and those from other sources examined, such differences could easily be due to natural variation between individual deposits *within* the Badakhshan region itself. Lapis lazuli is mined there at multiple points along an intermittent zone of mineralization that is approximately 20 km long (Hermann 1968: 22-24). Keisch and Callahan conducted a sulfur isotope study (1976) of ultramarine that included geologic samples from the Badakhshan deposits and their results suggested that there was a great deal of isotopic variability along that zone. Therein is a second area of weakness in both Casanova's and Ballirano and Maras' datasets – the number of samples and their representativeness. The potential range of chemical variability across the

extensive Badakhshan lapis lazuli deposits simply cannot be adequately assessed based on the small number of samples they analyzed from that source (seven by the former and three by the latter). It is not even clear if their samples represented a single mine or several individual ones. The same is true, for that matter, of the Badakhshan lapis lazuli samples that showed so much isotopic variability in Keisch and Callahan's study. They wrote that "it would be of considerable interest to analyze samples from each of the mines in Badakhshan" (Keisch and Callahan 1976: 518).

One final word on this matter: By being skeptical of a lapis lazuli source in the Chagai Hills it is not my intention to impugn the reliability of those who originally provided samples attributed to that region (Hassan and Lizioli) or to find fault with Casanova or Ballirano and Maras, who did outstanding work given the number and nature of the geologic samples available to them. I just believe that this ancient luxury stone is too important to accept anything less than well-documented confirmation that another source of it existed. It would be thrilling if it could be confirmed that lapis lazuli actually occurred in the Chagai Hills. If the stone did somehow form in the Chagai Hills then there is reason to expect[2) that it would be chemically and/or isotopically distinguishable from that occurring in the Badakhshan region. The existence of two viable sources would have tremendous implications for studies of ancient trade and interaction from South Asia to Egypt. But all of the available evidence presented strongly suggests that lapis lazuli does not and cannot exist in the Chagai Hills. Even so, additional geologic fieldwork in the region and further analytical studies of samples are always warranted.

2) The oldest rock formations in the Chagai Hills date to the later Cretaceous Period (ca. 145 to 65 Ma) while the Badakhshan lapis lazuli deposits occur in ca. 2700-2400 Ma Archean rock (Faryad 2002: 726).

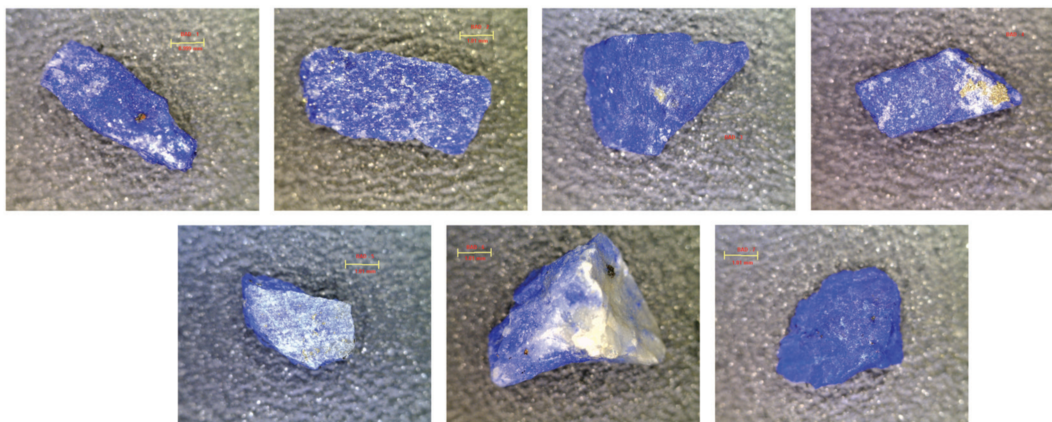
## A SULFUR ISOTOPE STUDY OF LAPIS LAZULI ARTIFACTS AND SOURCE SAMPLES

### The sample set

Both Jean-François Jarrige and Maurizio Tosi generously provided me with samples of the "Chagai Hills" lapis lazuli that they had obtained from Hassan and Lizioli respectively. During my research work in Quetta, I had also purchased a few pieces that ostensibly came from the same region. I wished to compare this "Chagai Hills" lapis lazuli to samples from confirmed sources in order to determine if they were geochemically distinct in any way. Keisch and Callahan's excellent study (1976) showed that there often were clear differences (ibid: Fig. 3) in the sulfur isotope composition of samples from different sources (for instance between those from occurrences in Afghanistan, Russia and Chile). If the "Chagai Hills" samples were isotopically distinct then, perhaps, there could be a source in that region after all. Such differences would, at the very least, suggest that there probably is somewhere a second viable source of lapis lazuli for Indus Civilization peoples. In order to test this possibility, a small set geologic source samples and artifacts was assembled (Appendix 4.4 Figure 5).

Back in 1999, when I was in Irkutsk, Russia nearby Lake Baikal, I purchased a number of raw lapis lazuli samples that I was told were from the sources documented in the Sayan Mountains, which are located immediately to the southwest of the lake. A few years later, during my various research periods in Peshawar, Pakistan, I obtained numerous pieces of the stone that I could be fairly certain had been brought to the city's bazaars directly from sources in the Badakhshan region. And recently, I bought a piece of lapis lazuli from a rock dealer in Vienna that is supposed to be from one of the sources in the Mogok region of Myanmar. The irony that, since I did not collect them myself, the provenances of these geologic source samples are, in reality, not that much better

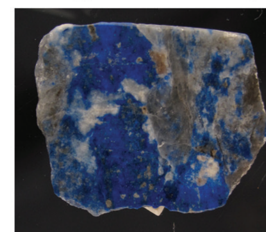
Badakhshan samples



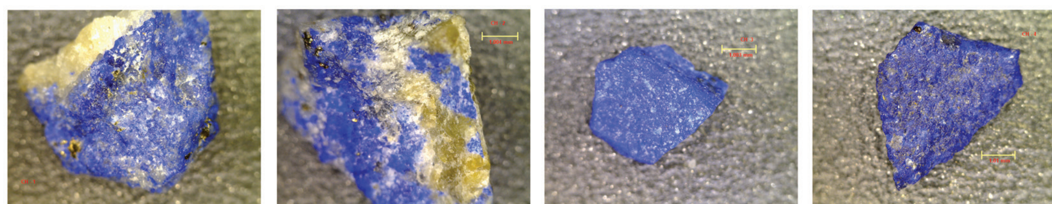
Baikal samples



Mogok sample

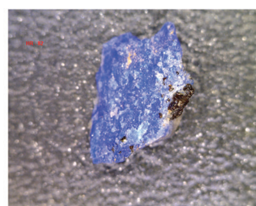


“Chagai Hills”? samples

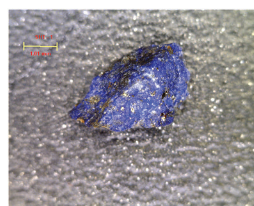


Artifacts

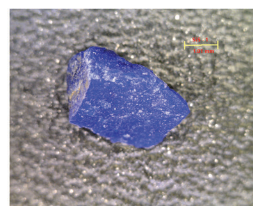
Harappa



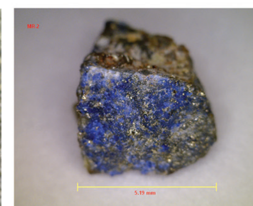
Shortughaï



Shahr-i-Sokhta



Mehrgarh



**Appendix 4.4 Figure 5** Lapis lazuli source samples and artifacts isotopically assayed for this study.

than those from the “Chagai Hills” is not lost on me. However, at least for the Baikal and Badakhshan samples, I did obtain them from merchants in cities where one would expect that genuine materials from those sources would be gathered and sold (in the case of Peshawar this is well known to be true). As for Wilhelm Niemetz’s rock shop in Vienna, I can only say that he had an exceptional collection of specimens from around the world including many from Myanmar.

I also analyzed lapis lazuli artifacts from four archaeological sites for this study. Jean-François

**Appendix 4.4 Figure 6** $\delta^{34}S$ ‰ and $\delta^{18}O$ ‰ values for lapis lazuli source samples and artifacts.

| sample | source/site | $\delta^{34}S$ ‰ | $\delta^{18}O$ ‰ |
|---|---|---|---|
| BAD-1 | Badakhshan, Afghanistan | 16.7 | 19.7 |
| BAD-2 | Badakhshan, Afghanistan | 16.8 | 20.2 |
| BAD-2P | Pyrite extracted from BAD-2 | 12.2 | not analyzed |
| BAD-3 | Badakhshan, Afghanistan | 19.0 | 20.6 |
| BAD-4 | Badakhshan, Afghanistan | 23.1 | 19.4 |
| BAD-5 | Badakhshan, Afghanistan | 16.3 | no sample left |
| BAD-6 | Badakhshan, Afghanistan | 14.5 | 15.3 |
| BAD-7 | Badakhshan, Afghanistan | 23.4 | 15.2 |
| BK-1 | Baikal, Russia | 41.3 | 18.8 |
| BK-2 | Baikal, Russia | 54.8 | 19.0 |
| BK-3 | Baikal, Russia | 52.8 | 19.3 |
| CH-1 | Chagai Hills? - Purchased in Quetta | 18.9 | 19.7 |
| CH-1P | Pyrite from extracted from CH-1 | 12.3 | not analyzed |
| CH-2 | Chagai Hills? - Jarrige/Hassan sample | 19.3 | 20.3 |
| CH-3 | Chagai Hills? - Tosi/Lizzioli sample | 13.5 | 19.3 |
| CH-4 | Chagai Hills? - Tosi/Lizzioli sample | 15.2 | 19.0 |
| Burma-1 | Mogok area, Myanmar | 4.5 | not analyzed |
| Burma-2 | Mogok area, Myanmar | 4.1 | not analyzed |
| HR-82 | Harappa, Pakistan | 24.5 | 20.3 |
| SIS-1 | Shahr-i-Sokhta, Iran | 19.4 | 18.3 |
| SHT-1 | Shortughaï, Afghanistan | 16.7 | 19.4 |
| MR-2 | Mehrgarh, Pakistan | 13.3 | 15.5 |

Jarrige kindly provided debris fragments from both the Indus Tradition settlement of Mehrgarh and the Harappan site of Shortughaï. If stone from the Chagai Hills of western Balochistan was traded into the Indus region then some of it is very likely to have ended up at Mehrgarh, which is located at the foot of the most prominent pass connecting the Balochistan highlands to the Indus Valley. A Chagai Hills lapis lazuli source, if it really existed, would have also been significantly closer and more accessible to peoples at that site than deposits in the Badakhshan region (300 km due west of Mehrgarh over reasonably traversable terrain versus over 800 km due north over some of the most dangerous mountain passes on earth). The site of Shortughaï in northern Afghanistan sits near the lower reaches of the Kokcha River, the upper reaches of which run directly through the Sar-i-Sang lapis lazuli mines. Out of all Harappan sites, it is there that one would most expect to find stone from the Badakhshan area deposits. Maurizio Tosi kindly provided a fragment recovered during his excavations of Shahr-i-Sokhta in eastern Iran. This site is again significantly closer to the supposed Chagai Hills source. Finally, a lapis lazuli fragment that was surface find from Harappa was analyzed.

Altogether, the set of lapis lazuli samples

(Appendix 4.4 figures 5 and 6) consisted of a single fragment from each of the four archaeological sites just discussed and 18 geologic samples. Seven of the geologic samples were from the Badakhshan deposits, three were from the Baikal deposits, one was from the Mogok area and four were attributed to a source in the Chagai Hills (one purchased in Quetta by me, one from Jarrige and two from Tosi). Material from two opposite sides of the Mogok lapis lazuli sample was removed for two separate analyses. Pyrite crystals from two of the geologic samples were extracted (for reasons discussed below) and analyzed separately as well. Sulfur isotope analysis, which is relatively inexpensive and fast, was the method selected based on Keisch and Callahan's successful study (1976).

### Sample preparation and analysis

Lapis lazuli almost invariably contains inclusions of pyrite. After a conversation on this matter with Massimo Vidale in 2007, it was decided that an attempt should be made to separate the pyrite from the lazurite in each sample prior to analysis. The reasoning was that sulfur isotope characteristics of the lazurite (sodium calcium aluminum silicate sulfur sulfate) and pyrite (iron sulfide) components of lapis lazuli might not necessarily be the same. This would not be a significant problem if the proportions of these minerals were identical from sample to sample. However, the amount of pyrite in lapis lazuli can vary considerably (see the photographs of the samples in Appendix 4.4 Figure 5), even within a single specimen. Let us assume for the moment that the sulfur isotope values for pyrite and lazurite within individual samples and deposits are indeed different from one another. If two pieces of lapis lazuli from the same source were analyzed, one of which contained a few flecks of pyrite while the other was rife with it, then the sulfur isotope composition of heterogeneous samples taken from the two pieces would likely be different as well. It was because of this possibility that it was deemed prudent to try, inasmuch as was possible, to separate the two minerals.

Each lapis lazuli sample was ground to a fine powder in an agate mortar. The powders were then placed into individual plastic vials that had wide mouths and conical-shaped bottoms. Enough purified water was added to the vials to cover the powder with at least 1 cm of liquid. Vials were then covered and placed into a shallow ultrasonic bath that thoroughly mixed the contents. The lids were removed and the vials were put into a drying box overnight so that the water could evaporate. Pyrite has a specific gravity of around 5.1 while the density of lazurite is between 2.3 and 2.4. It was hoped that the much denser pyrite would collect in the constricted bottoms of the vials while the lighter lazurite would settle toward the top. There are other methods to separate the pyrite that involve magnetizing it by heating so that it could be removed using a magnet (Uslu and Arol 2003). The problem is that some of the sulfur that would be needed for isotopic analysis would probably be driven off in the process (Gunter 1909: 117). In the end, the method used here seemed to work reasonably well. The blue powder that settled at the top seemed to be free of pyrite, unlike the grayer blue residue that collected at the bottom of the vial.

It was decided to test the theory that lazurite and pyrite in a single specimen might have different sulfur isotope values. Material from two of the geologic samples (BAD-2 and CH-1) was coarsely ground and pyrite crystals were removed by hand to be analyzed separately.

Sulfur analysis of the sample set was conducted by Dr. Chris Eastoe at the Isotope Geochemistry Laboratory, University of Arizona. Each sample was dissolved in HCl and then a $BaCl_2$ solution was added to precipitate $BaSO_4$, which as then filtered and dried (Isotope Geochemistry Laboratory 2004). Sulfur dioxide gas was extracted from the $BaSO_4$ by combustion with $V_2O_5$ (Yanagisawa and Sakai 1983) in a Costech elemental analyzer. From that gas $\delta^{34}S$ values were measured a Finnigan Delta PlusXL continuous

flow gas-ratio mass spectrometer. International sulfur standards OGS-1 and NBS123 were used along with several other sulfide and sulfate materials that have been compared between laboratories. Based on repeated use of internal standards the precision was estimated to be ± 0.15 or better (Chris Eastoe *personal communication* 2004). The results of the sulfur isotope analyses of the geologic and archaeological samples are listed in the third column of Appendix 4.4 Figure 6. They are expressed using the notation $\delta^{34}S$ ‰, which represents the per mil (‰) deviation in the $^{34}S/^{32}S$ ratio measured in the sample compared to that measured in the Canyon Diablo Troilite (CDT) meteorite international standard (Eckhardt 2001: 514). Oxygen isotope analysis was also conducted by Dr. Eastoe on most of the samples in the set. Those results, although listed here in the fourth column of Appendix 4.4 Figure 6, did not prove to have any value in terms of differentiating the various samples by their geologic sources.

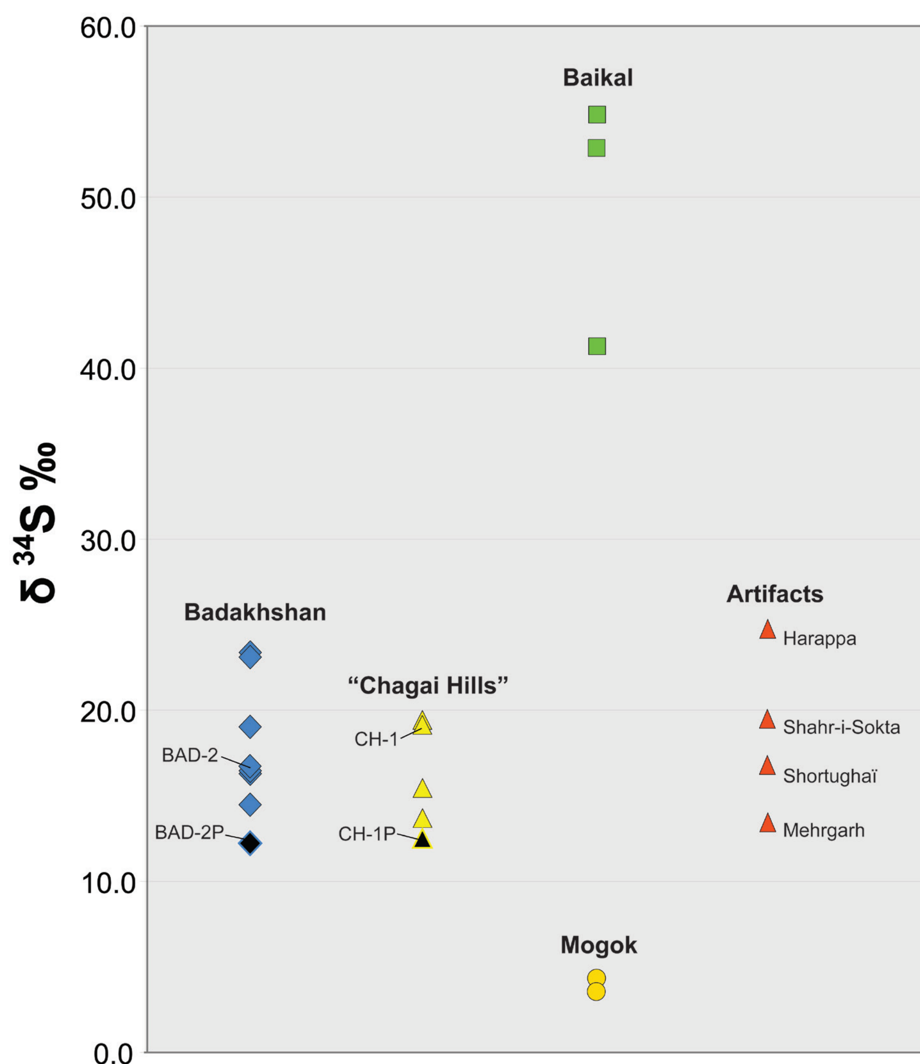
## Results

The results of the sulfur isotope analysis of the geologic and archaeological lapis lazuli sample set are plotted in Appendix 4.4 Figure 7. It is immediately clear that the Badakhshan, Baikal and Mogok source samples are very distinct from one another. The $\delta^{34}S$ ‰ values of the seven Badakhshan lazurite samples range from 14.5 to 23.4 (a variation of 8.9), the three Baikal samples ranges from 41.3 to 54.8 (a variation of 13.5) and the Mogok sample that was analyzed twice ranged from 4.1 to 4.5 (a variation of 0.4 in a single specimen). The "Chagai Hills" lazurite samples, which range from $\delta^{34}S$ ‰ 13.5 to 19.3, overlap significantly with those from the Badakhshan region. The either means that the source from which they came has the same isotopic characteristics as the lapis lazuli deposits of northern Afghanistan or that they are actually from the Badakhshan region. Given what we know of about the geology of the Chagai Hills and the questionable provenances of the samples themselves, I believe the latter scenario to be more likely.

So if we discount the "Chagai Hills" samples as representative of a separate source (which at this point I have) then all four of the archaeological lapis lazuli fragments appear most closely related to samples from the Badakhshan region. The $\delta^{34}S$ ‰ value for the Harappa fragment is slightly greater (by 1.1) than the highest Badakhshan sample value while the fragment from Mehrgarh is slightly lower (by 1.2) than the lowermost value. However, it is doubtful that the analysis of a mere seven geologic samples captured the full range of isotopic variation exhibited across that extensive source area. The incorporation of additional samples from the Badakhshan deposits will very likely extend the range of variation for that source area and encompass isotopic values of the Harappa and Mehrgarh artifacts.

The distinct isotopic characteristics of the Mogok sample suggests that it is genuinely representative of a separate lapis lazuli source. Moreover, none of samples from the multiple deposits (in Afghanistan, Tajikistan, Russia, Italy, Chile and the USA) analyzed by Keisch and Callahan have similar sulfur isotope values (see Keisch and Callahan: Fig. 3). This specimen is probably indeed from a source in Myanmar. Analyses of additional samples are obviously needed, however. The range of isotopic variation will almost certainly expand when further assays of the Myanmar source are conducted. If the specimen analyzed here happens to be on the lower range of variation and the source varies similarly to the Badakhshan and Baikal occurrences, then the higher range of the Mogok source sulfur isotope values could overlap with the lower ones of Badakhshan.

Interestingly and importantly, the pyrite crystals extracted from two lapis lazuli samples in the set (these are noted with black symbols and are labeled on Appendix 4.4 Figure 7) did indeed have sulfur isotope values that were different from those of the lazurite components in the very same specimens (also




**Appendix 4.4 Figure 7** Sulfur isotope values ($\delta^{34}S$ ‰) plotted for lapis lazuli source samples and artifacts.

labeled on Appendix 4.4 Figure 7). Pyrite from the Badakhshan sample (BAD-2 / BAD-2P) had a $\delta^{34}S$ ‰ value that was 4.6 lower while that for "Chagai Hills" sample (CH-1 / CH-1P) was 6.6 lower. Although this is not enough difference to result in a misclassification of artifacts between the sources examined here, it is significant because it shows that the amount of pyrite in a specimen will probably affect the results. So it is indeed advisable to separate it out inasmuch as possible. After the analyses presented here were completed, I learned (in Craddock 2009: 412) that for their study Keisch and Callahan actually analyzed pyrite from lapis lazuli samples rather than the lazurite component (this is not stated in their 1976 paper on the subject). Had I known, I too would have done this. While the separation technique I used seemed to work reasonably well, I could not be certain that I extracted all of the pyrite from the lazurite. Extracting the small but highly visible crystals would have been much easier and would have likely resulted in a purer sample.

The sulfur isotope results published by Keisch and Callahan became clearer once I understood that they had analyzed extracted pyrite and I discovered that the sulfur isotope values for that mineral were generally lower than they are for lazurite in the same samples. In their published chart of the isotopic ranges for the lapis lazuli sources they analyzed (Keisch and Callahan 1976: Fig. 3), both the Baikal and Badakhshan occurrences had somewhat lower values than I detected in my analyses of lazurite from those same sources. My results would have likely

been more or less the same as theirs had I analyzed extracted pyrite instead.

## RECENT LAPIS LAZULI PROVENIENCE RESEARCH USING OTHER TECHNIQUES

The question "Where does lapis lazuli come from?" continues to intrigue scholars. This was actually the title of a fairly recent paper by Zöldföldi and others (2006). Using non-destructive prompt gamma activation analysis (PGAA), they studied lapis lazuli samples from sources in Afghanistan, Russia (Baikal and the Ural Mountains) and Chile. They found the Ural and Chilean samples to be quite distinct but had more trouble differentiating Afghanistan and Baikal samples. More recently, Smith and Klinshaw (2009) examined the infrared spectra of lazurite in lapis lazuli samples from Afghanistan, Canada, Myanmar, Lake Baikal, Tajikistan, and the Ural Mountains. They found that a weak band in the spectra at 2340 $cm^{-1}$, which had once been considered to be a marker of stone from the Badakhshan region (Derrick *et al.* 1999: 137), was actually present in lapis lazuli from several other source areas and, thus, was not a good indicator of raw material from Afghanistan. Also recently, Lo Giudice and others (2009) employed cathodoluminescence (CL), scanning electron microscopy (SEM) and micro-Raman spectroscopy in their study of lapis lazuli samples from Afghanistan, Tajikistan, Chile, and the Baikal area. Among other things, they found that Tajikistan source samples exhibit several distinct features ("an additional luminescence band at 690 nm ... a cancrinite phase with a strong UV emission and a vibronic structure with ZPL at 2.55 eV" – Lo Giudice and others 2009: 2217) and Baikal samples can be distinguished by their unusually high barium and strontium contents.

These recent studies are important because, although none have proven to differentiate the lapis lazuli deposits of Asia any better than sulfur isotope analysis, some of the methods employed in them could be used in combination with sulfur isotope analysis when an overlap between two sources occurred. I am specifically referring to the small lapis lazuli deposit located at Ishkashim in the Pamir Mountains of Tajikistan. It is my feeling that this occurrence was probably too minor and too inaccessible (situated at 4600 meters in elevation on a precipitous cliff face – Ivanov and Sapozhnikov 1985: 17) to have been a very important source. However, it is located only around 130 km northeast of the Sar-i-Sang mines, which themselves are pretty high up (ca. 2500 meters – Wyart *et al.* 1981: 187) and not easily reached. The Ishkashim deposit, therefore, should not be disregarded entirely. The single sample from that source analyzed by Keisch and Callahan had a value of around $\delta^{34}S$ ‰ 13, which is near the middle of the range (ca. $\delta^{34}S$ ‰ 10 to 18) of the isotopic variation that they defined for the Badakhshan deposit (see Keisch and Callahan 1976: Figure 3). For future studies, it might be possible to differentiate Badakhshan lapis lazuli from that of the Ishkashim deposit by keying in on one of the several distinct features of raw material from the latter that were identified by Lo Giudice and others (2009).

## CONCLUSION

Based on the evidence and analysis presented above, my answer to Prof. Durrani's question today would be that the Sar-i-Sang deposits in the Badakhshan region of northern Afghanistan would likely have been the only viable sources of lapis lazuli for Harappans or their contemporaries in the Near East. I base the latter part of this statement, in part, on that fact that in their paper, Keisch and Callahan related (1976: 518) that they had "also analyzed some samples of archeological interest that were found in

Mesopotamia and are reported to be 3000 to 4000 years old." Although they did not note the names the sites from which the artifacts originated, they did state that the lapis lazuli "also probably came from Afghanistan" (ibid).

# APPENDIX 4.5

# THE "ERNESTITE" PROBLEM

## "ERNESTITE"

I have had numerous debates (sometimes impassioned but always good-natured and constructive) with Dr. Mark Kenoyer regarding the problem of the nature and origins of "Ernestite" – a type of rock that Harappans used to make drill bits for perforating hard stone beads. Kenoyer feels that it is some unusual type of metamorphic rock, which perhaps has not been previously described by geologists. It was for this reason that he and Massimo Vidale (Kenoyer and Vidale 1992) gave it the informal designation "Ernestite" in honor of Ernest Mackay (*Mackayite* was already being used for another mineral) who first described drill bits from Chanhu-daro made of this material (Mackay 1937: 6-7). I have had the opportunity to conduct a series of follow-up analyses of "Ernestite" and have come to a different, albeit still provisional, conclusion. My research suggests that "Ernestite" is probably a type of *indurated tonstein flint clay* that has been deliberately heated in order to produce or enhance properties in the stone that made it a highly effective material for drilling hard stone beads. In this appendix, I present my case for making this designation.

Let me begin by restating and expanding my introduction to the material from Chapter 4. "Ernestite" is an extremely fine-grained stone with dark-brown to black patches and/or dendritic veins in a khaki-colored matrix (see examples of raw "Ernestite" from Harappa in Appendix 4.5 Figure 1). It is hard (easily scratching quartz but not topaz giving it a Mohs hardness of at least 7 but less than 8), very tough (does not break or fracture easily) and fairly dense (SG ranging from ≈ 2.8 for the khaki-colored matrix to ≈ 3.2 for the brown-black portion). It was made into drill bits, many of which have a distinctive constricted cylindrical form (Appendix 4.5 Figure 2). These were used by Indus beadmakers to perforate hard stone (namely microcrystalline silicates and vesuvianite-grossular). As far as I have been able to determine, drill bits made from this rock and having this distinctive form are nearly unique[1] to the Indus Civilization sites. Ernest Mackay (1937) first discovered them among bead-making materials at the site of Chanhu-daro in Sindh (Appendix 4.5 Figure 3). Drill bits of the exact same shape, along with the raw material used to make them, were later identified at Harappa and Mohenjo-daro (Kenoyer and Vidale 1992). A huge number are present in the stone and metal artifact assemblage of Dholavira[2] (Bisht and Prabhakar 2008). I have seen "Ernestite" drill bits in collections of excavated materials from Harappan sites elsewhere in Gujarat like Kanmer, Shikarpur, Khirsara and Lothal. I fully expect that many more such artifacts will be discovered as old collections are re-examined and new Harappan sites are excavated.

The raw material from which these drill bits are made would *seem* to be similarly unique. Using XRD and EMPA, Kenoyer and Vidale (1992) characterized it as a metamorphic rock composed of quartz, sillimanite-mullite and hematite-titanium oxide phases. Unable at the time to identify a known

1) A single drill of this description was found at the city of Ur in Mesopotamia, leading Ernest Mackay to speculate that it was "not at all unlikely that bead-making in Sumer was carried on by Indian craftsmen" (1943: 212).

2) The exquisitely fashioned black constricted cylindrical drill bit from Dholavira that is published (as jasper) in the catalog for the 2000 "Indus Civilization Exhibition" in Tokyo (NHK 2000: 106, Figure 598) is one of them.




**Appendix 4.5 Figure 1** Raw "Ernestite" fragments from Harappa.




**Appendix 4.5 Figure 2** Constricted cylindrical drill bits made from "Ernestite".




**Appendix 4.5 Figure 3** "Ernestite" drill bits and long biconical carnelian beads from the site of Chanhu-daro. Photo by J. M. Kenoyer, with permission from the Boston Museum of Fine Arts.

rock type with those phases, they proposed the name "Ernestite."

For this study, four "Ernestite" fragments recovered on Mound E at Harappa (H2000/2090-49, H2000/3317-2 to 4) were selected for study using XRD and EMPA with the hope that further characterization might shed new light on the identity of this stone, its geologic origins, potential sources and the properties that made is the most effective material available to Harappans for drilling hard-stone beads.

## XRD ANALYSIS OF "ERNESTITE"

Two of the four "Ernestite" samples (H2000/2090-49 and H2000/3317-4) examined using XRD were mainly made up of the khaki-colored primary matrix and had only small patches of the black-brown material. These samples displayed diffraction peaks showing that they were composed primarily of quartz and mullite-sillimanite (see Appendix 4.2 I for one of these scans). Minor peaks indicative of *hematite* (iron oxide) and *rutile* (titanium oxide) were also present. *Mullite* and *sillimanite* are actually two separate aluminum silicate minerals that have nearly identical XRD peak profiles (Brown 1980: Table 6.21; Varley 1968: 3). The XRD profiles of the two samples were ambiguous – meaning that they seemed to have peaks characteristic of both minerals and could have been interpreted as either. The same was true of the Mohenjo-daro sample analyzed by Kenoyer and Vidale, which they characterized using a combined term – "sillimanite-mullite" (1992: 507). It is possible that both minerals exist in the samples or, perhaps, than an aluminum silicate phase intermediate to mullite and sillimanite is present (Cameron 1976; Bradley and Roussin 1932). It is also possible that what has been detected in the XRD scans is a poorly crystallized, early stage of mullite formation (Chakraborty *et al.* 2003).

The remaining two "Ernestite" samples (H2000/3317-2 & H2000/3317-3) were composed

largely of the darker material that occurs in veins and patches. The XRD scans unambiguously showed it was the mineral mullite that was present in these fragments (see Appendix 4.2 J for one of these scans). Peaks for quartz, hematite and rutile (present in the previous two samples) were not to be found, however. Instead, strong peaks for *cristobalite* – the high temperature polymorph of quartz, were evident.

The minerals in these samples provide important clues into the possible origins of "Ernestite." Sillimanite occurs in highly metamorphosed *argillaceous* (clay-rich) rocks known as *pelites* (Deer *et al*. 1992: 52). It is not an uncommon mineral and can be found in rocks of this type occurring at points throughout the Himalayas of northern Pakistan and India (Das 1984; Khan *et al*. 1997) as well as across Rajasthan (Bhattacharyya 1980; Goel and Chaudhari 1979). Mullite also forms in metamorphosed argillaceous rocks (Deer *et al.* 1992: 54) but, in contrast to sillimanite, it is an exceedingly rare mineral in nature. To my knowledge, no natural occurrences in South Asia have ever been reported. Mullite is, however, a very common man-made mineral. It is both an intentionally produced *refractory* material (a substance able to withstand high temperatures without melting or vitrifying) and a byproduct of certain high-temperature crafts and industries. Mullite can be synthesized when the other aluminum silicate minerals (sillimanite, kyanite and andalusite) are heated to temperatures exceeding 1350°C (Industrial Minerals 1998: 139). However, mullite also forms when aluminum-rich clays (such as *kaolinite*) and claystones are subjected to sufficient heat – generally this is around 1100°C but may be somewhat higher or lower depending on the composition of the raw material, the atmosphere and firing dynamics (Brindley and Nakahira 1959; Castelein *et al*. 2001: 2369; MacKenzie *et al*. 1996; Russell 1965; Saunders 1958; Schneider *et al*. 1994: 107). Interestingly and importantly, experimental heating studies (Dubois *et al*. 1995; Donley 1955: 3; Liu 1990: 5; Lundin 1958; Russell 1965: 45; Worrall 1975: 16) of kaolinitic clay bodies reveal that amorphous silica, which is freed during kaolinite-to-mullite conversion, will crystallize as cristobalite. This has been observed at temperatures as low as 1100°C (Brindley and Nakahira 1959). The mineral quartz alone will also convert to cristobalite when heated. Experimental studies (using controlled atmospheres and sample purities) have shown that this conversion occurs slowly between 900°C and 1200°C and rapidly after 1300°C (Sosman 1965: 132-133). Like mullite, cristobalite is a common mineral byproduct in certain high-temperature craft industries. Cristobalite has been previously detected in studies of Harappan high-temperature craft industries such as stoneware bangles (Vidale 2000: 90), faineance objects (McCarthy and Vandiver 1991: 502) and steatite beads (Barthélémy de Saizieu 1994: 56).

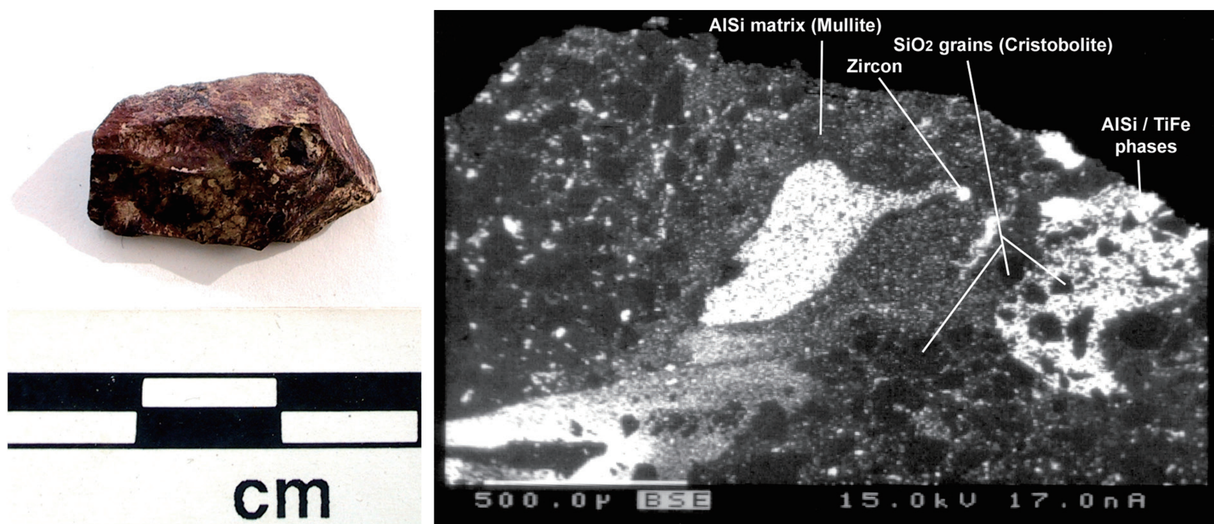
The advanced pyrotechnological capabilities of Indus craftspeople are well-documented (Miller 1999) and the presence of these two high-temperature minerals in the "Ernestite" samples analyzed here would seem to suggest that it may have been yet another of the many materials that Harappans heat treated. If it was, then what type of stone might the original material have been? Further characterization studies were conducted using EMPA in order to address this question.

## EMPA OF "ERNESTITE"

The four "Ernestite" samples from Harappa, as well as the one from Mohenjo-daro studied by Kenoyer and Vidale in 1992, were examined using the backscatter electron (BSE) imaging, energy dispersive spectrometry (EDS) and wavelength dispersive spectrometry (WDS) capabilities of the electron microprobe. Appendix 4.5 figure 4 and 5 are labeled BSE images of portions of two of the "Ernestite" fragments, which may serve as visual references as I




**Appendix 4.5 Figure 4** "Ernestite" fragment H2000/2090-49 (left). BSE image of black patch (right).




**Appendix 4.5 Figure 5** "Ernestite" fragment H2000/3317-2 (left). BSE image of main body (right).

discuss the mineral phases and inclusions (labeled on the figures) that, in most cases, were detected in each of the five samples. Appendix 4.5 Figure 6 is a table of WDS scans that were selected to represent the phases and inclusions identified.

WDS scans of the primary, khaki-colored matrix (the darker phases in the BSE images) of "Ernestite" showed it to be composed of clay-sized (< 2 µm) or smaller particles of an aluminum silicate (Al-Si) mineral. This would be the phase identified in the XRD scans as mullite or mullite-sillimanite. The darker matrix (lighter phases in the BSE images) that occurs in veins and patches is also an Al-Si phase. However, in some samples this matrix is rich in hematite (iron oxide) and/or contains small phases or inclusions hematite and rutile (titanium oxide). In other samples, an oxide of titanium and iron called *titanohematite* is interspersed among the darker Al-Si matrix. Titanohematite only begins to form at temperatures of around 1050°C (Deer *et al*. 1992: 541). It is highly significant that this phase is evident in the same samples (H2000/3317-2 & H2000/3317-3) in which two other high-temperature minerals (mullite and cristobalite) were identified using XRD.

Among the light and dark Al-Si matrixes that make up the main body of ernestite are sub-euhedral grains and fragments of $SiO_2$ up to 100 µm in size. These are the quartz or cristobalite phases detected

in the XRD analyses (EMPA cannot differentiate the two of types of quartz as they are chemically identical polymorphs). Using EDS scans only, small (≈ 20 μm) inclusions of zircon (the brightest white spots on the BSE image) were identified, as well as occasional minute phosphate phases that contained the rare earth elements (REEs) yttrium (Y) and cerium (Ce). The texture of "Ernestite," as seen in the BSE images also provides clues to its possible origin. The stone's matrix is composed of randomly oriented clay-sized Al-Si particles into which fairly well-sorted sub-euhedral grains and fragments of $SiO_2$ are set. These are detrital attributes that point to a rock of sedimentary origin. There is no evidence of characteristics one would expect to see if this was a metamorphosed rock such as foliation, deformation or re-crystallization. Nor are there any obvious metamorphic minerals such as are evident in the massive, compact rock composed of altered sillimanite found near Rewa in northern Madhya Pradesh (Banerjee and Sirgar 1961). Remnants of the prismatic, needle-like structure that is characteristic of sillimanite in thin-section (MacKenzie and Adams 1994: 180-181) can clearly been seen in the Rewa rock (Banerjee and Sirgar 1961: Figure 1). Nothing of the sort is evident in the BSE images of "Ernestite," however. This suggests that the somewhat ambiguous "mullite-sillimanite" phases detected in two samples using XRD is almost certainly *not* heat-transformed sillimanite. Instead, those phases most likely represent a poorly crystallized, early stage of mullite formed from the heating of the clay-sized Al-Si material that makes up the stone's matrix.

## WHAT IS "ERNESTITE"?

Based on results of the XRD and EMPA characterization studies, I believe that "Ernestite" is a variety of *claystone* known as a *tonstein* and that it was heat-treated by Harappans to produce properties in the stone that made it an extremely effective material for drilling hard stone beads. In this section, I present my case for making this designation.

*Claystone* (sometimes called clayrock) is a general term for *non-fissile* sedimentary rocks (those that are not laminated and do not split along bedding planes) that are composed of *indurated* (a term synonymous with lithified or cemented) "clay-size silicate minerals" (Blatt 1992: 490; Lapidus and Winstanley 1990: 108). "Ernestite" – a tough, non-fissile stone primarily made up of clay-sized Al-Si particles, clearly falls into this category. Claystones vary in their origins, compositions and degrees of induration (Loughnan 1978). The variety known as *flint clay* is composed mainly of tightly interlocking kaolinite crystals (Moore and Reynolds 1997: 143), which makes it extremely tough and gives it a very fine-grained to microcrystalline texture along with a conchoidal to sub-conchoidal fracture (Keller 1968). The stone is named as it is because, obviously, these traits provide it with physical properties and an appearance that mimics flint (chert). It can easily be knapped like that material and then further shaped by grinding and engraving. In many parts of ancient North America, flint clay was a popular stone for making ornaments, effigies and, significantly, smoking pipes (Emerson and Hughes 2000; Hughes *et al*. 1998; Wisseman *et al*. 2002). Using a claystone of this sub-variety, Harappans could have easily fashioned constricted cylindrical drills by the chipping and grinding method described by Vidale (2000: 56).

Most flint clays are also *fire clays* (although not all fire clays are as highly indurated as flint clay). A fireclay is a common refractory material composed of an aluminous clay mineral (normally *kaolinite*) with small amounts of free silica (quartz) and other impurities (of which iron oxide and anatase are of particular importance here), which can withstand temperatures as high as 1750°C without vitrifying or deforming (Dodd and Murfin 1994: 120-121, 125; Lapidus and Winstanley 1990: 215). Although

**Appendix 4.5 Figure 6** Select WDS scans of "Ernestite" fragments

| | Light Matrix | Darker Matrix | Fe Phase (Hematite) | Ti Phase (Rutile) | Titanohematite Phase | $SiO_2$ Phase |
|---|---|---|---|---|---|---|
| MgO | 0.05 | 0.20 | 0.18 | 0.00 | 0.26 | 0.00 |
| $Al_2O_3$ | 39.25 | 48.10 | 6.36 | 0.50 | 4.94 | 0.19 |
| $SiO_2$ | 59.28 | 40.56 | 7.25 | 0.30 | 1.24 | 98.57 |
| CaO | 0.04 | 0.59 | 0.03 | 0.00 | 0.00 | 0.00 |
| $TiO_2$ | 0.21 | 0.25 | 1.56 | 95.66 | 33.39 | 0.08 |
| MnO | 0.00 | 0.00 | 0.07 | 0.01 | 0.06 | 0.00 |
| FeO | 1.07 | 4.61 | 74.45 | 1.00 | 51.85 | 0.22 |
| $Na_2O$ | 0.06 | 0.90 | 0.01 | 0.00 | 0.00 | 0.00 |
| $K_2O$ | 0.08 | 0.64 | 0.01 | 0.01 | 0.02 | 0.01 |
| $Cr_2O_3$ | 0.01 | 0.02 | 0.30 | 0.07 | 0.14 | 0.00 |
| ***total*** | ***100.04*** | ***95.87*** | ***90.21*** | ***97.55*** | ***91.89*** | ***99.07*** |

kaolinite peaks were not detected in the XRD analyses, there are multiple lines of evidence, in addition to its appearance, toughness and texture, which suggests that "Ernestite" is a type of indurated kaolinitic fire clay that has been heat-treated. To begin with, as has been previously discussed, the heating of aluminous clays and claystones produces very characteristic high-temperature minerals. After 600ºC, the structure of kaolinite becomes disordered and, in a *solid-state* (Castelein *et al.* 2001; Russell 1965), passes through several amorphous (or nearly amorphous) forms (Leonard 1977) until it begins to re-organize as mullite starting at around 1100º C. The mullite phases detected in the "Ernestite" samples are composed of clay-sized Al-Si particles that, in all likelihood, were once kaolinite, but that have been transformed in this way. Similarly, cristobalite is a common by byproduct of heated refractory clays (Davison and Heystek 1979). The phases of that mineral evident in the "Ernestite" samples with well-crystallized mullite could be a product of kaolinite-to-mullite conversion and/or the high-temperature transformation of natural quartz impurities contained within the original claystone – perhaps a combination both. It is also possible that cristobalite was a component of the original, unheated stone (discussed further below).

Other mineral impurities detected in the samples provide supporting evidence that "Ernestite" is a type indurated fire clay and help to explain the variation that is seen between the phase compositions of the stone's lighter and darker Al-Si matrixes. Iron oxide is an important minor component of fireclays (especially in levels greater than three percent) because it enhances mullite formation by acting as a fluxing element with aluminum silicate (Keller 1968: 116). It was not at all surprising, therefore, when EMPA indicated the darker Al-Si matrix of "Ernestite," which exhibited the best developed peaks for mullite in the XRD scans, had refractory levels of iron oxide (Appendix 4.5 Figure 6 column 3). Mullite was more poorly-developed in the samples composed of the lighter-colored Al-Si matrix, which had lower concentrations of iron oxide (Appendix 4.6 Figure 2 column 2). Another common impurity in fireclay is *anatase* ($TiO_2$), which is the low temperature

polymorph of rutile. Anatase converts to rutile after being heated above 730ºC (Deer *et al*. 1992: 550). The rutile that was detected using XRD in the two lighter matrix "Ernestite" samples is *perhaps* heat-transformed anatase (it may also have been present in the original, unheated stone – see below). This anatase/rutile would have contributed the titanium component of the high-temperature titanohematite phases detected in the darker matrix samples. The zircon inclusions and phosphate phases containing REEs that were detected using EMPA provide still more clues to the identity and origin of "Ernestite." Fire clays were formed in swampy, non-marine environments either from the accumulation of detrital kaolinitic sediments or from the in-situ kaolinitazation of fallen volcanic-ash (Admakin 2002; Keller 1968; Loughnan 1978). The term *tonstein* is widely used to denote the variety formed in the latter manner (Bohor and Triplehorn 1993). The first studies that I read regarding claystones of this type were eye-opening, because it was as if I was reading descriptions of "Ernestite." Tonsteins possess *all* of the properties that I have outlined above for fire clays *as well as* zircon inclusions and phosphate phases with concentrations of REEs – two traits that are indicative of their volcanic parentage (Bohor and Triplehorn 1993; Hower et. al 1999). In fact, cristobalite and rutile derived from the diagenesis of volcanic ash are also lithogenetic indicators of tonsteins (Admakin 2001: 24). It is therefore possible that those two minerals were original components of "Ernestite" and did not form due to heating (although heating of the stone still took place as demonstrated by the presence of mullite and titanohematite). Because tonsteins formed in swampy, plant-rich environments, they frequently contain casts of rootlets and other organic materials, which give them a mottled appearance (Bohor and Triplehorn 1993: 26-27). This may account for the characteristic appearance[3)] of "Ernestite", with its dark patches and dendritic veining.

In summary, the appearance, toughness, texture (both macroscopic and microscopic) and composition of "Ernestite" are all consistent with the category of highly indurated claystone known as flint clay. Most flint clays are also kaolinitic fire clays that, when subjected to sufficient heat, produce a very characteristic mineral – mullite, which is highly uncommon in nature but a ubiquitous byproduct of high-temperature crafts and industries involving aluminous clays and claystones. Its presence, along with titanohematite phases, strongly suggests that "Ernestite" was *deliberately* heated. Cristobalite and rutile phases detected in the stone may also be products of heat-treatment. Or, they could be further evidence of its volcanic parentage, which is clearly indicated by the presence of zircon inclusions and REE-rich phosphate phases. Kaolinitic claystone formed from the diagenesis of volcanic ash fallen in a swampy, non-marine environment is known as a tonstein. This is what "Ernestite" appears to be.

At least that is my working hypothesis. I have been unable to find any reference to another type of naturally occurring sedimentary, igneous, or metamorphic rock possessing the same combination of characteristics reported here. Of course it is entirely possible that "Ernestite" is a variety of stone that has not previously been encountered and described by geologists. I consider that to be very unlikely, however. Its physical properties are highly consistent with a tonstein, which belongs to a category of kaolinitic claystones that are well known to geologists. The changes kaolinitic materials undergo when heated are equally well-documented and well understood. Although studies will continue, *a highly indurated tonstein flint clay that has been heat-*

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3) The "Ernestite" drill bit and raw material assemblage at Dholavira is much more macroscopically variable, which may indicate that the beadmakers of that site may have dwelled near the source or sources of this stone and exported only a certain sub-variety of it to craftsmen at Harappan settlements elsewhere.

*treated* is the most fitting characterization that can be made for "Ernestite" at this time. The concern now is to determine where exactly Harappans might have acquired raw material of this kind.

## WHERE DOES "ERNESTITE" COME FROM?

Tonsteins are variable in terms of their color, texture, mineral constituents and degree of induration (Bohor and Triplehorn 1993). Identifying the precise occurrence(s) that was used as a raw material source for "Ernestite" drills will require a great deal of exploration and sample testing. The latter will be necessary because if "Ernestite" was heat-treated (I believe the evidence demonstrates that it was) then it is very likely that the original, unheated tonstein, wherever it is located, will have somewhat different visual and physical properties, as any substance composed primarily of clay minerals does prior to being fired. Samples collected from potential sources will first need to be experimentally heated to determine if the physical appearance and properties of "Ernestite" can be replicated. Then they will need to be fashioned into drills to evaluate their effectiveness at perforating hard stone such as agate and vesuvianite-grossular. The problem of locating potential sources is made somewhat easier by the fact that tonsteins and other fire clays were formed in swampy, non-marine environments rich in organic matter and so are almost invariably found in association with coal beds (Bohor and Triplehorn 1993; Loughnan 1978: 380; Hoehne 1976).

Although the term "tonstein" has, up until now, rarely been used in the geologic literature of South Asia, occurrences of claystones or fire clay seams in coal beds have been noted in many different areas around the Greater Indus region (Bender 1995b: 276; Kazmi 1995a: 206-218; Talati and Desai 1978). In the spring of 2003, I traveled throughout northern Gujarat examining and sampling the many fire clay deposits of that area (Bhatti and Chavda 1977; Rahalkar and Madhukara 1980). One occurrence that I was particularly hopeful might be a raw material source for "Ernestite" is located near Guneri (Chavda and Joshi 1990) in the Lakhpat district of western Kutch, not far (≈ 20 km) from where a Harappan Period site has been identified (IAR 1960-61: 8). The samples of dark gray-colored fire clay collected from that location and the four others I visited in northern Saurashtra, were extremely fine-grained but rather soft (as compared to "Ernestite"). After being fired at 1200°C for one hour, their colors ranged from light khaki to an almost pure white and, although they became significantly harder, they were light in weight and somewhat brittle. Although these deposits obviously did not provide the raw material that I was seeking, the overall physical appearance of samples from them, aside from their color, in many ways resembled the larger fragments of "Ernestite" recovered at Harappa. This further convinced me that Harappans were using a variety of sedimentary claystone to make constricted cylindrical drill bits, rather than a metamorphic rock. I simply had not yet located a coal bed containing a tonstein claystone that was sufficiently indurated to begin with. Other potential occurrences can be found in every province of Pakistan (Kazmi *et al.* 1990; Shah *et al.* 1990; Warwick and Husain 1990). Some of those where refractory clays and claystones are noted (Baqri 1978) lay deeply buried and so would not have been accessible to Harappans. Coal beds are, however, exposed on the western flanks of the Kirthar Range in Sindh (Blanford 1879: 192-193) and I have been told (S.R.H. Baqri *personal communication* 2004) that very hard, flint-like claystones can be found in the vicinity of Sehwan. Claystone seams in accessible coal beds are also reported in the western and central part of the Salt Range (Shah 1980: 82-84; Whitney *et al.* 1990: 3).

Although the search for Ernestite" will continue in all of the above areas, my feeling at this stage is that the Harappan source likely lies somewhere in northern

Gujarat. I have recorded over 1200 "Ernestite" drill bits in my studies of the collection of excavated materials from the site of Dholavira. Compare this to the 75 artifacts in total (both drill bits and debris) that have been recovered at Harappa. The shear abundance of "Ernestite" at Dholavira would seem to indicate that beadmakers there had access to a local (on Khadir Island) or regional (elsewhere in Kutch) source of the stone.

## "ERNESTITE" AS A DRILL-MAKING MATERIAL

What properties did heat-treated tonstein flint clay possess that appealed to Harappan beadmakers? Experimental studies by Kenoyer and Vidale (1992) have shown that it would have been possible for them to perforate a hard stone like carnelian almost three times faster using an "Ernestite" drill bit than it would have been using one made from a microcrystalline silicate like jasper or chert ("Ernestite" abraded carnelian at an average rate of 2.37 mm per hour compared to .83 mm per hour for green jasper). This unequal drilling efficiency probably has little to do with differences in hardness between the two materials. Quartz has a Mohs hardness of around 7 and so does mullite – the hardest major mineral in "Ernestite" (zircon has a hardness of 7.5 but there is not enough of it in the stone to have contributed significantly to its cutting effectiveness). The properties that make "Ernestite" much more effective than chert or jasper for drilling hard stone beads are its *durability*, *strength* and *heat-resistance*.

Harappans would have found drills made of a microcrystalline silicate to be more than effective tools for perforating steatite, lapis lazuli, serpentine or any other variety of stone with a Mohs hardness of less than 7. However, as Kenoyer and Vidale discovered (1992: 504-505), when used on a stone of equal hardness such as agate, both the shaft of the drill and the hole of the bead being perforated wear to a high polish. Abrading effectiveness rapidly diminishes as this occurs. In contrast, the inter-locking clay-sized Al-Si particles of "Ernestite" make it an extremely durable (wear-resistant) material. In the 1930s, C.H. Desch carried out a drilling experiment (noted in Mackay 1943: 211) on carnelian using a bit recovered from the site of Harappan Period site of Chanhu-daro in Sindh. At the time, the bit was thought to be made of chert but it is now known be composed of "Ernestite." After drilling carnelian to a depth of 1 mm in around 20 minutes (an abrading rate roughly comparable to what Kenoyer and Vidale recorded for "Ernestite"), Desch found the wear on the tool "to be very slight" (ibid.). Scanning electron microcopy (SEM) studies by Kenoyer and Vidale (1992: 508) revealed that drills made of durable "Ernestite" do not become polished during use like microcrystalline silicates. Instead, they maintain a rough micro-surface and, thus, an undiminished cutting capacity.

In addition to being durable, "Ernestite" is an extremely well-bonded material, which can be made into drills that, although delicate-looking, are very strong. Perforating the distinctively Harappan style of long (≈ 7 to 10 cm) carnelian beads was accomplished using a graduated series of three or four long and progressively thinner "Ernestite" drill bits (Kenoyer and Vidale 1992: 511). One example that Ernest Mackay reported (1943: 211 *footnote* and Plate LXXXVI b, #8, drill e) from Chanhu-daro was 1.5 inches (3.81 cm) in length but only 0.12 inches (3.05 mm) in diameter. Although fashioning a drill bit of similar dimensions out of chert or jasper would have been possible, such a tool would likely not have lasted for long under the stress of drilling as the "raw material is very brittle and tends to flake very easily and snap" (Kenoyer and Vidale 1992: 503).

Microcrystalline silicate drills are also plagued by frequent incidences of spalling due to the heat generated by the friction of drilling, as well as a tapered design that makes cooling the tool during use

difficult (Kenoyer and Vidale 1992: 505). Tiny heat-spalled drill bit tips made of jasper and chert are very common finds in areas at Harappa where hard stone beads were made (Meadow *et al.* 2001: 7). A tool made from a refractory material like tonstein flint clay, on the other hand, would be extremely resistant to the effects of heat. The biggest testament to this is that no heat-spalled "Ernestite" drill tips have ever been found at Harappa (J.M. Kenoyer *personal communication* 2002).

The "secret" to "Ernestite's" durability, strength and resistance to heat is mullite. The remarkable mechanical and refractory properties of this mineral are well-documented (Osendi and Baudín 1996; Mah and Mazdiyasni 1983; Schneider *et al* 1994; Schneider and Komarneni 2005). Mullite "imparts uniformly high strength" to those materials in which it forms, as well as a "high resistance to thermal spalling, i.e, resistance to breaking or cracking when heated" to extreme temperatures (Keller 1968: 119-120). There is a modern industry devoted to deliberately synthesizing it for applications that require a material having this specific combination of properties (Industrial Minerals 1998; Johnstone and Johnstone 1961; Schneider and Komarneni 2005). Mullite would not have been originally present in the tonstein(s) used as a raw material for "Ernestite." That stone likely attracted the attention of Harappans looking for drill-making material because it was already a tough, highly indurated rock (as most flint clays are). Sometime around the middle part of the Integration Era (ca. Period 3B at Harappa), perhaps even earlier, it was discovered that by heating tonstein flint clay to a temperature that probably exceeded 1100°C it was possible to produce or enhance properties (discussed above) in the rock that made it a superior material for drilling hard stone beads. Although Harappans could not have known that the reason for this was that its structure of tightly inter-locking kaolinite crystals was being made even stronger and more heat-resistant by the solid-state transformation of those crystals into mullite, they were evidently well aware of which parts of the stone had most benefited from the heat-treatment. The majority of finished "Ernestite" drill bits recovered at Harappa and other Indus sites were made largely or entirely from the stone's less abundant black matrix, which the XRD scans showed have the best developed mullite phases.

## CONCLUSION

There is still great deal of work to be done on the "Ernestite" problem. Although I feel strongly that the identification "tonstein flint clay that has been heat-treated" is, currently, the best explanation for the macroscopic, mineralogical and mechanical characteristics possessed by "Ernestite," I realize that many (including myself) will not be entirely convinced of this until a source of tonstein flint clay is located in the Greater Indus region, material from that sources is heated to temperatures that should result in the formation of mullite, then that heat-treated material is fashioned by chipping and grinding into replicas of Harappan constricted cylindrical drill bits and finally it is shown that those drills are capable of perforating agate or vesuvianite-grossular at a rate of better than 2 mm an hour or better without breaking or spalling. If that can be done and the resulting material *looks* like "Ernestite" then I will be convinced.

## ADDENDUM - A SMALL TEST

Having read the above section, Prof. Kenoyer felt that I had not adequately demonstrated that "Ernestite" was heat-treated. He suggested that I heat a piece of it in a muffle furnace to a temperature hot enough for mullite and cristobalite to form (≈ 1100 to 1200° C) in order to see if its appearance changed. He argued that if the material had been previously heat-




**Appendix 4.5 Figure 7** Before and after images of an "Ernestite" chip that has been heated to 1200° C.

treated in this way then its appearance after being re-heated should remain unchanged. So I took a small (≈ 1.75 x 2.75 cm) chip off of one of the larger pieces of "Ernestite" and heated it slowly (a dynamic firing where the temperature was steadily raised 200° C per hour) to 1200° C. The chip was allowed to dwell at 1200° C for two hours after which the furnace was turned completely off and left to cool slowly overnight.

The next day the "Ernestite" chip was removed from the cooled furnace and examined. Appendix 4.5 Figure 7 is a composite photo that shows the chip's unheated appearance (left) next to how it looked after being fired slowly to 1200° C (right). There is a *slight* difference in the before and after images. The khaki-colored matrix is a shade lighter as are some patches of the darker matrix. I can think of two reasons why the stone's color might have become slighter lighter. Firstly, the chip is from an artifact that has been buried for 4000 plus years. "Ernestite" is dense, yes, but is still basically a claystone that is somewhat permeable. "Ernestite" artifacts may actually have darkened slightly over the last four millennia as they picked up organics from the moisture laden soils at Harappa. Firing the chip may have simply burned off some of the organics it picked up. Moreover (and secondly) the muffle furnace was an oxygen-rich environment. "Ernestite" contains iron phases, the heaviest concentrations of which are in the darker portions of the stone. Had the chip been fired in a reducing atmosphere then the iron oxides in it might have remained dark or, perhaps, even become darker.

In the end, the chip's appearance was little changed and the firing experiment was inconclusive. In my opinion, the biggest testament to "Ernestite's" heat-treatment by Harappans remains the presence of mullite and cristobalite – two minerals that are rare nature (even rarer together) but are common in clays and claystones heated to high temperatures.

# APPENDIX 4.6

# A LATE HARAPPAN KAOLINITE BEAD

## DISCOVERY

Trench 38 (Appendix 4.6 Figure 1 A) was placed on the north side of Mound AB in one of the few areas at Harappa where Late Harappan (Period 5) or "Cemetery H" Phase architecture was still, more or less, intact after the extensive brick robbing of the mid-1800s (Kenoyer 2005b: 32-37). During the 1996 excavation season, a small pot that had been buried in the floor of house (Appendix 4.6 Figure 1 B) from this period was recovered. The interior of the pot (Appendix 4.6 Figure 1 C) was carefully excavated by J.M. Kenoyer (Appendix 4.6 Figure 1 D) and found to contain a cache of 133 beads (Appendix 4.6 Figure 1 E). These artifacts have provided a number of insights into trade and technology during the Late Harappan Period (ibid: 37-39). Of particular interest is object H96/7330-15 – a small red bead (indicated by a red arrow on Appendix 4.6 Figure E).

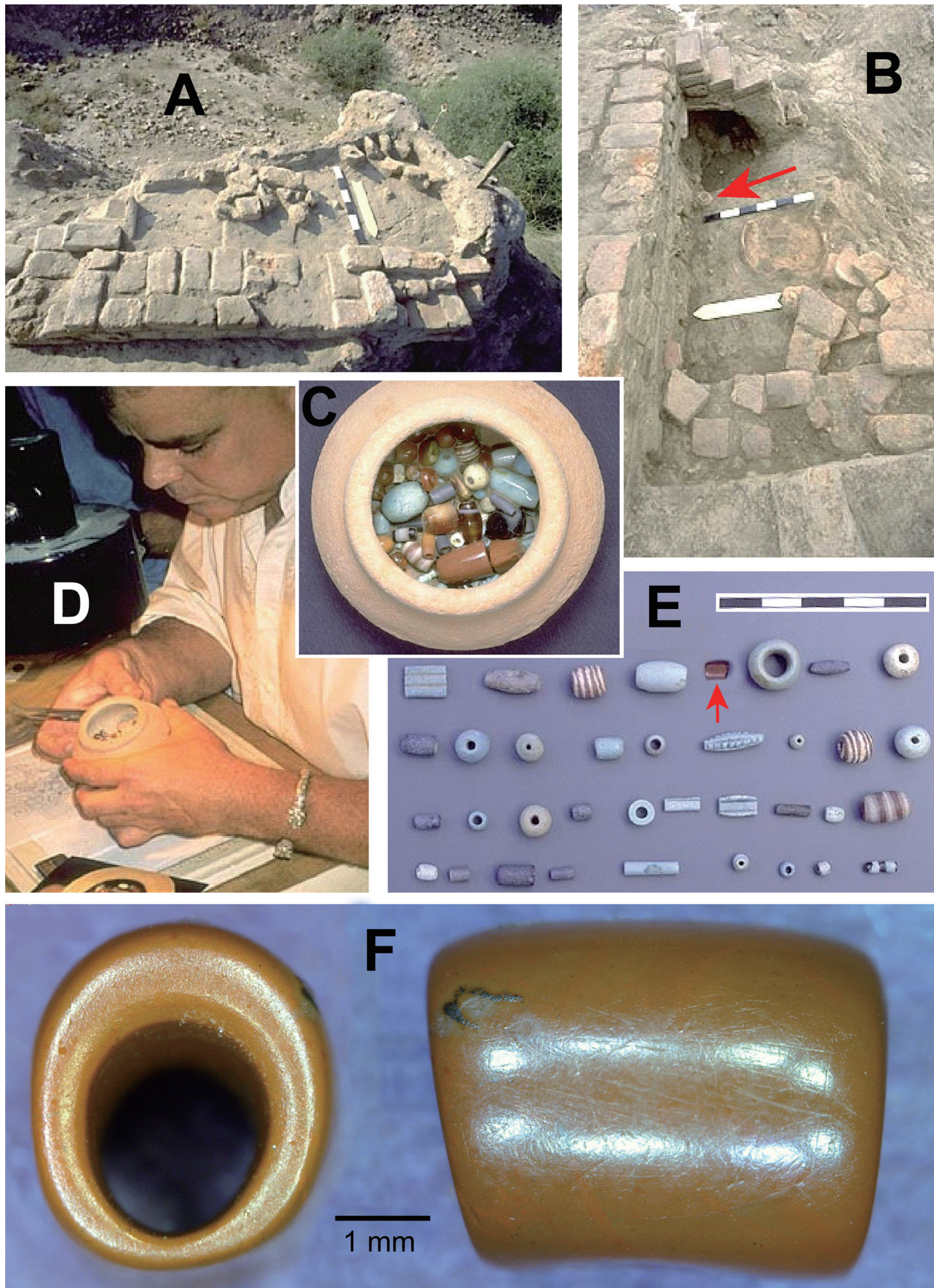
## IDENTIFICATION

The red bead in question was initially thought to be as carnelian but closer examination (Appendix 4.6 Figure 1 F) suggested that it might actually be an early form of glass (Kenoyer 2005a: 167; Kenoyer 2005b: 37-38). It has a polished, glassy sheen and a dark bubbly-looking patch that seemed as if it could have been the vestiges of the glass manufacturing process. This would have made the bead the earliest evidence for glass-making in South Asia. However, its identification as glass was only provisional until such time as further, positive analyses could be conducted. With the permission of Dr. Fazal Dad Kakar, Director-General, Department of Archaeology and Museums, Government of Pakistan, the bead was brought to the University of Wisconsin-Madison in 2009 for non-desctructive analysis using variable pressure scanning electron microscopy (VP-SEM) and X-ray diffraction (XRD).

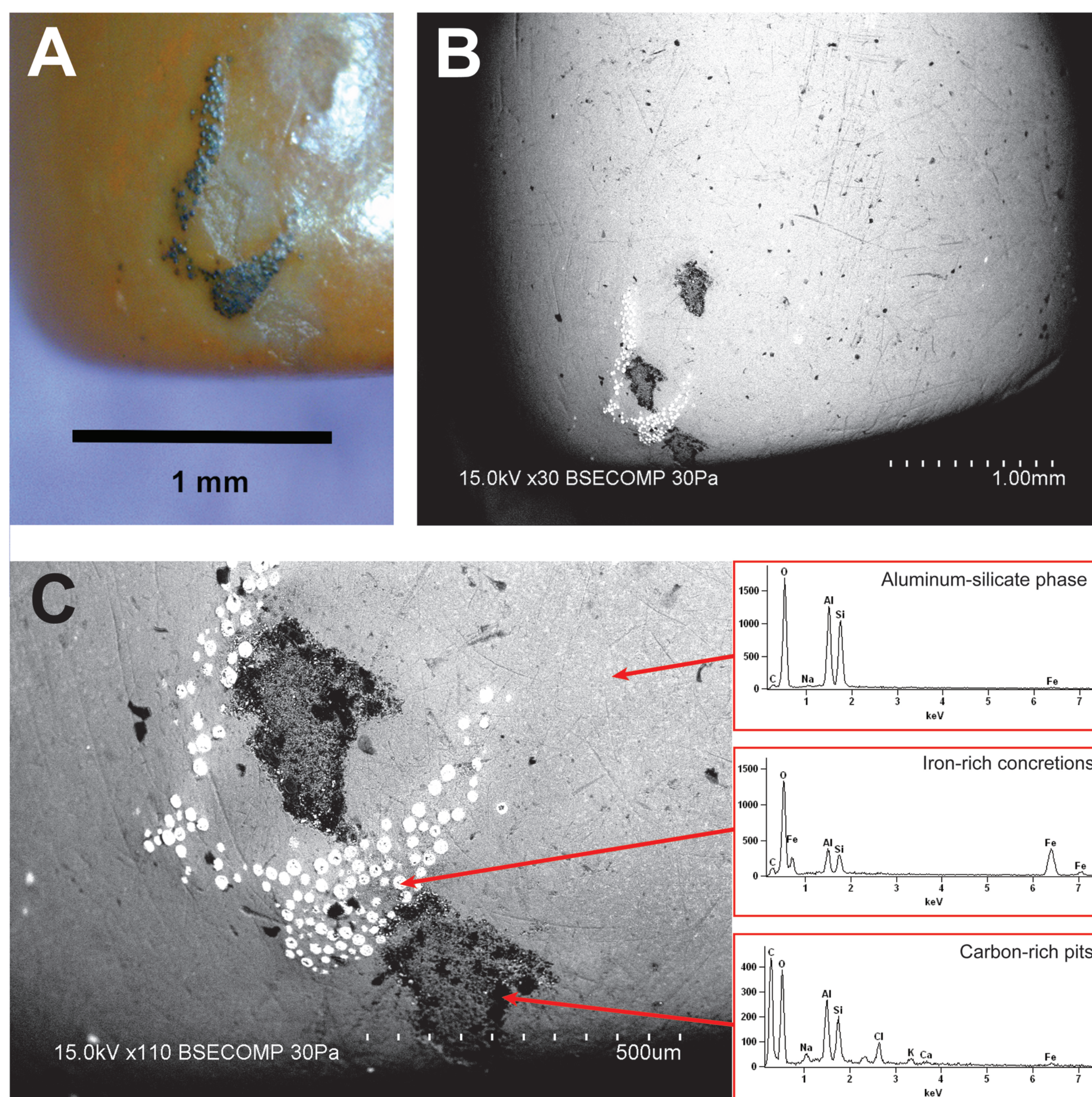
### VP-SEM

The variable pressure scanning electron microscope (VP-SEM) is a wonderful tool for non-destructive characterization of artifacts. With it is possible to micro-image samples without having to first coat them with a current conducting material such as carbon or gold, as is necessary with conventional scanning electron microscopy (SEM). Moreover, the Hitachi S-3400N VP-SEM at the Eugene Cameron Electron Microprobe Lab in the Department of Geoscience, University of Wisconsin-Madison is equipped with a Thermo Electron energy dispersive spectrometer (EDS) and so it is possible to do qualitative evaluations of the composition of the artifacts being examined.

Analysis of the red bead focused on and around the dark bubbly patch (seen in visible light in Appendix 4.6 Figure 2 A). Back-scatter electron imaging (BSE) of that area (Appendix 4.6 Figure 2 B) revealed that the main body of the object, while fairly smooth and homogenous, is spotted with a few large and many small depressions or pits filled with a substance having a relatively low atomic number (the pits appear dark gray or black because materials with low atomic numbers appear darkest in BSE images while those with higher ones appear brighter). The bubbly patch is made up of spherical nodules or concretions with an atomic number much higher than the main body or the pitted area (thus they appear white in the BSE image).




**Appendix 4.6 Figure 1** **[A]** During the excavation of Trench 38 on the north side of Mound AB. **[B]** a small pot (indicated by a red arrow) was found embedded in a Late Harappan (Period 5) house floor. **[C]** The pot contained a cache of beads, **[D]** which were carefully excavated by J.M. Kenoyer. **[E]** Among the artifacts found in the pot was a small red bead (indicated by a red arrow) **[F]** with a polished, glassy sheen and a dark bubbly-looking patch (visible on the upper left corner of the right-hand view of the bead).
Images A through E are from the website Harappa.com and are used with the permission of J.M. Kenoyer.

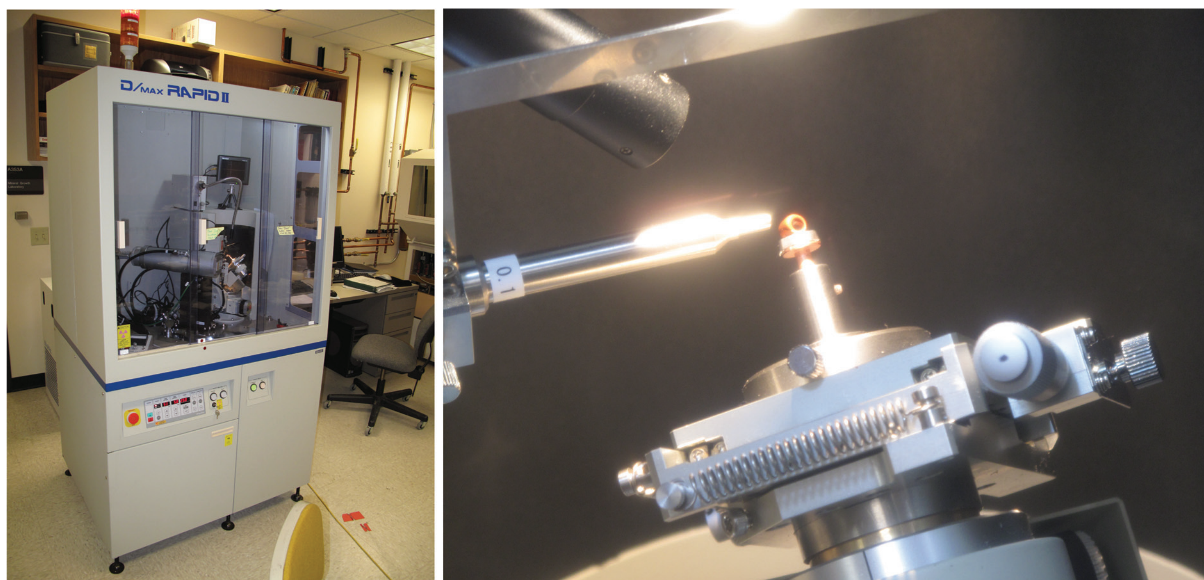


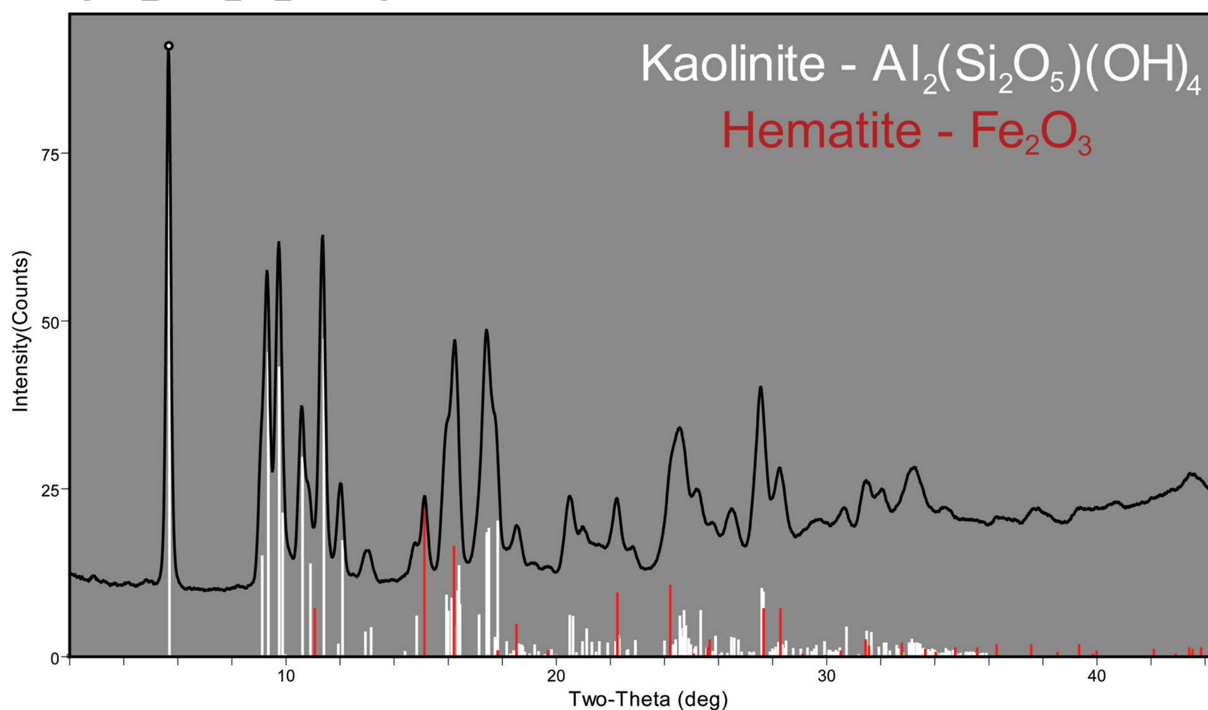

**Appendix 4.6 Figure 2** **[A]** Visible light image of the small red bead's black patch. **[B]** BSE image of the small red bead's black patch showing that it is made up of spherical concretions. **[C]** EDS spectra of bead's primary matrix, the spherical concretions and tiny pits/depressions in the bead's surface.

EDS scans were made of three points on the red bead (Appendix 4.6 Figure 2 C). These revealed that the main body of the object was an aluminum silicate mineral of some kind, the spherical concretions making up the dark bubbly patch were rich in iron, and the pits were high in carbon. It was immediately obvious that <u>the artifact was *not* a glass bead</u>. What it was made from was not entirely clear, however. The aluminum silicate composing the main body of the bead could have been any number of minerals including kyanite, sillimanite, andalusite, mullite, kaolinite and pyrophyllite. The concretions were thought to be hematite and the pits might have contained graphite. Positive mineralogical identification of these phases would require a different technique.

## XRD

In September of 2009, the S.W. Bailey Memorial XRD Laboratory in the Department of Geoscience, University of Wisconsin-Madison acquired a state-of-the-art Rigaku Rapid II XRD (Appendix 4.6 Figure




**Appendix 4.6 Figure 3** None-destructive XRD analysis of the Late Harappan red bead using the Rigaku Rapid II (top images). XRD spectrum (bottom) of the bead's primary matrix – kaolinite with a minor hematite phase.

3 *top left*). With this instrument, points down to 20 nanometers in size can be nondestructively analyzed on a sample, such as the late Harappan bead, in situ (Appendix 4.6 Figure 3 *top right*). Multiple scans of the red bead were made but all were basically the same. A representative scan is presented here (Appendix 4.6 Figure 3 *bottom*) The results indicate that bead is mainly composed of the mineral *kaolinite* (aluminum silicate hydroxide). Small peaks indicating the presence of hematite (iron oxide) were detected in every scan, but kaolinite always dominated, even in scans that were centered directly on the iron-rich spherical concretions. No minerals with a carbon component were detected. Thus, the carbon detected

in the pits is probably an amorphous carbon substance like wood ash rather than a mineral like graphite.

## CONCLUSION

The tiny red bead from the Late Harappan bead cache that was once thought to be glass now appears to have been made from a solid piece of indurated hematitic kaolinite. Kaolinite is a clay mineral which, in its form that develops plasticity when mixed with water, is widely used in the production of ceramics (Keller 1982; King 2009). However, the mineral can also occur in indurated (hardened) forms called *claystones* that will not slake in water and develop plasticity (Keller 1968; Loughnan 1978). We can be certain that bead was fashioned from a natural claystone rather than molded from a plastic clay that was then harded by heat (fired) because the act of heating transforms kaolinite into entirely new mineral phases – beginning around 550°C *metakaolinite* starts to form, a *spinel* phase is formed at 920°C, and finally *mullite* forms at around 1100°C (Bellotto *et al*. 1995a, 1995b). Had the bead been heated (if it was a ceramic bead) then one of these mineral phases would have been detected by XRD rather than kaolinite. As for the Fe-rich spherical concretions and hematite phases detected in the artifact, iron oxides are very common natural impurities in kaolinite bodies (Malden and Meads 1967). The reddish color of the bead is quite clearly related to the presence of iron and, thus, the raw material can aptly be described at hematitic kaolinite.

# APPENDIX 4.7

# THE IDENTIFICATION, CHARACTERIZATION AND POTENTIAL SOURCES OF A NEPHRITE JADE AMULET RECOVERED FROM THE CEMETERY AREA AT HARAPPA

## DESCRIPTION AND DISCOVERY

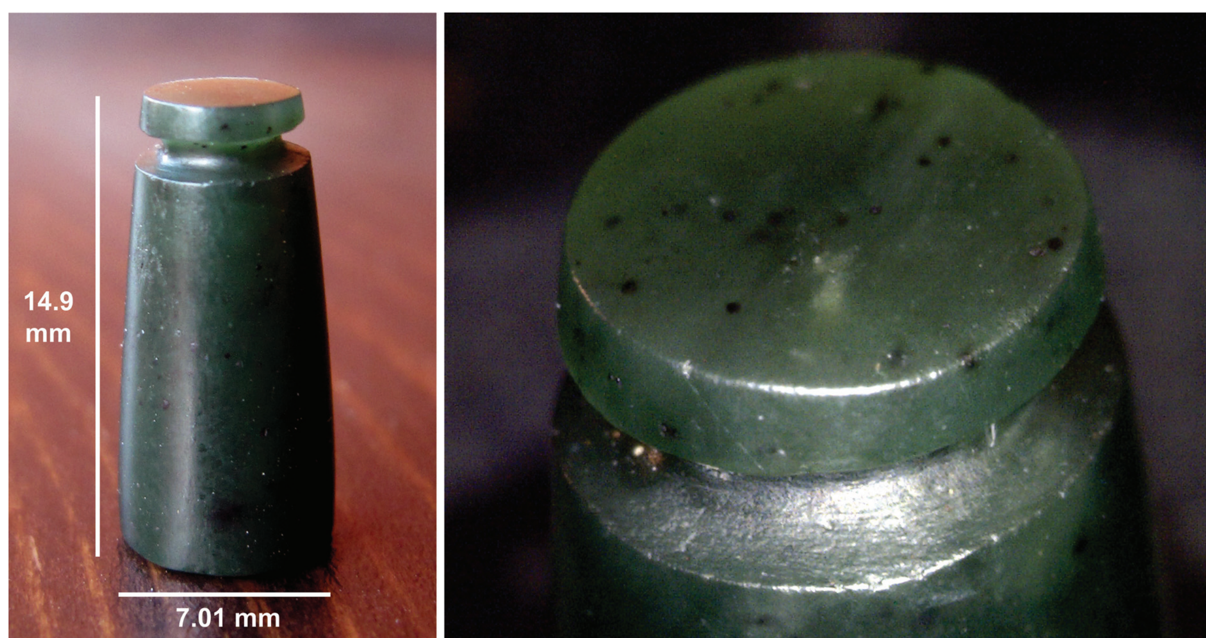
A semi-translucent, spinach-green colored truncated conical amulet (Appendix 4.7 Figure 1 *left*) was recovered from a cemetery area debris layer that directly overlaid a burial pit dated to Period 3B. Although the artifact may or may not date to that period, there is no question that it is from the Harappa Phase. Hundreds of objects (sometimes called "gamesmen") of the exact same form have been discovered at Indus Civilization sites but none are known from sites of earlier or later periods. The majority of such amulets are made from black basalt. Examples composed of other kinds of stone, including steatite, serpentine, alabaster, limestone and vesuvianite-grossular, are also found. The amulet under discussion here – artifact H88/182-14 – is notable for its high polish (especially around its grooved "neck") and distinctive black spots (Appendix 4.7 Figure 1 *right*).

## IDENTIFICATION AND CHARACTERIZATION

The amulet was originally thought to be composed of *serpentine* and was listed as such in the catalogue of the *Great Cities, Small Treasures* exhibit (Kenoyer 1998: 208) that came to the United States in 1998. This was an apt designation based on the object's visual characteristics alone. However, during my density testing of all green-colored stone artifacts from Harappa (described in Chapter 9) it was determined that the amulet had a specific gravity (SG) of 3.0, which is too dense to be serpentine (SG 2.7 to 2.8) or *quartz* (SG 2.6) and too light to be the *jadeite* form of jade (SG 3.24 to 3.43). A few examples of vesuvianite from Harappa with SG values of around 3.0 have been recorded but these are highly weathered debris fragments that have numerous fractures filled with chlorite. The material composing the amulet in question is unweathered and flawless. It also possesses a much deeper green color than is typical for vesuvianite-grossular and has a high, very "jade-like" polish. As it turns out, SG 3.0 is precisely the density of the tremolite-actinolite form of jade known as *nephrite* and so I provisionally designated the amulet as such in my dissertation (Law 2008a: 164-167). Further analyses were needed to confirm this identification, however. With the kind permission of Dr. Fazal Dad Kakar, Director-General, Department of Archaeology and Museums, Government of Pakistan, the artifact was brought to the University of Wisconsin-Madison in early 2010 for non-destructive identification and characterization using XRD and VP-SEM.

### XRD

The amulet was analyzed on the Rigaku Rapid II XRD in the Department of Geosciences, University of Wisconsin-Madison (Appendix 4.7 Figure 2 A). As nephrite jade is a variable rock in the tremolite-actinolite series (it is actually "nearly pure tremolite" with "variable amount of actinolite" – Liu 2010: 249), the XRD spectrum from this analysis was compared to the peak profiles for both end-member minerals (Appendix 4.7 Figure 2 B & C). All peaks in the amulet's spectrum were found to correspond very




**Appendix 4.7 Figure 1** Left - The semi-translucent, spinach-green colored truncated conical amulet – artifact H88/182-14 – recovered from a cemetery area debris layer at Harappa.
Right - Detail of the amulet's grooved neck and black inclusions.

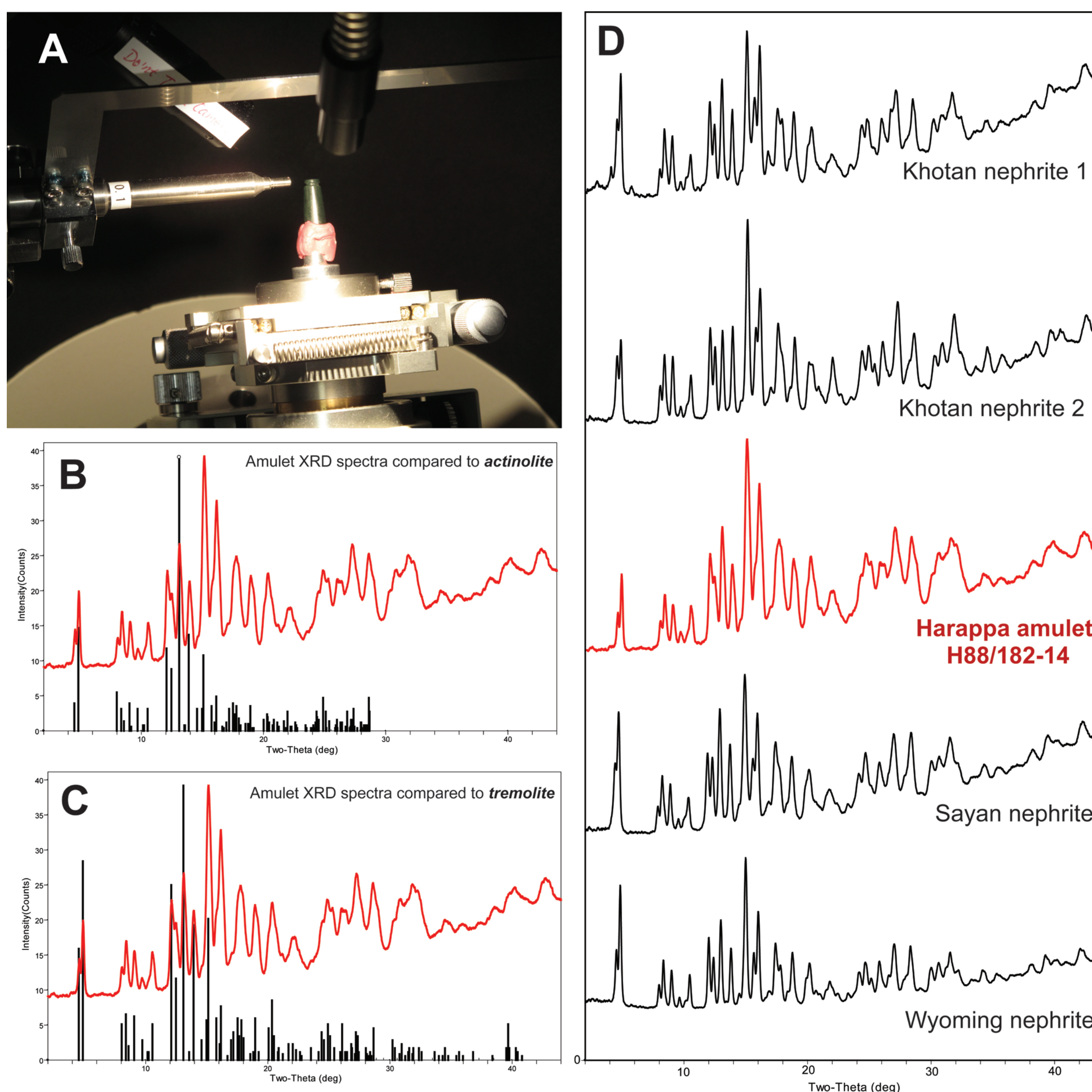
well to those of both actinolite and tremolite, which confirmed that it was indeed a rock that series.

For the next step, the amulet's XRD spectrum was compared to the spectra of several known examples of nephrite (Appendix 4.7 Figure 2 D). Two samples of that stone from the source near the city of Khotan (Hetian) in western China were analyzed along with samples from the Sayan Mountains of southern Siberia, Russia and the Granite Mountains of central Wyoming, USA. The peak profile of the amulet's spectrum closely matched those of each of these nephrite samples.

### VP-SEM

Further characterization of the amulet was conducted on the VP-SEM in the Department of Geosciences, University of Wisconsin-Madison. One distinquishing characteristic of nephrite is the tightly woven, matted fibrous texture it exhibits in microscopic images of fresh breaks and in petrographic thin sections (for examples see Bradt *et al* 1973: Figure 1 *top* and Twilley 1992: Figure 1). The highly polished surface of the Harappan amulet, which is evident in the BSE of the upper portion of the object (Appendix 4.7 Figure 3 A), largely obscures the natural texture of the stone. However, there are a few small unpolished areas (one is noted as E & F on the image) in which the rough surface of the raw material is visible. Close BSE imaging of one of these areas revealed a nephrite-like texture of tightly woven, matted fibrous crystals (Appendix 4.7 Figure 3 E & F).

Appendix 4.7 Figure 3 B is a BSE image of a portion of the top surface of the amulet on which several of stone's black inclusions are visible (these appear bright white on the image). EDS scans were made in this area of the amulet's primary phase and one of the inclusions (at the points noted as C & D respectively on the image). The peaks of Mg, Si, Fe and Ca evident in the spectrum of the primary phase (Appendix 4.7 Figure 3 C) are wholly consistent with nephrite (calcium magnesium iron silicate hydroxide). The peaks of Al, Fe and Cr evident in the spectrum of the inclusion (Appendix 4.7 Figure 3 D) are indicative of an aluminum-rich chromite (spinel) phase. Spinel-chromite inclusions such as these are not at all uncommon in nephrite (Hobbs 1982) and




**Appendix 4.7 Figure 2** **[A]** The amulet being non-destructively analyzed on the Rigaku Rapid II XRD. **[B]** The amulet's XRD spectrum compared to peaks for the mineral actinolite. **[C]** The amulet's XRD spectrum compared to peaks for the mineral tremolite. **[D]** The amulet's XRD spectrum was compared to the spectra of nephrite samples from Khotan, Sayan Mountains and Wyoming.

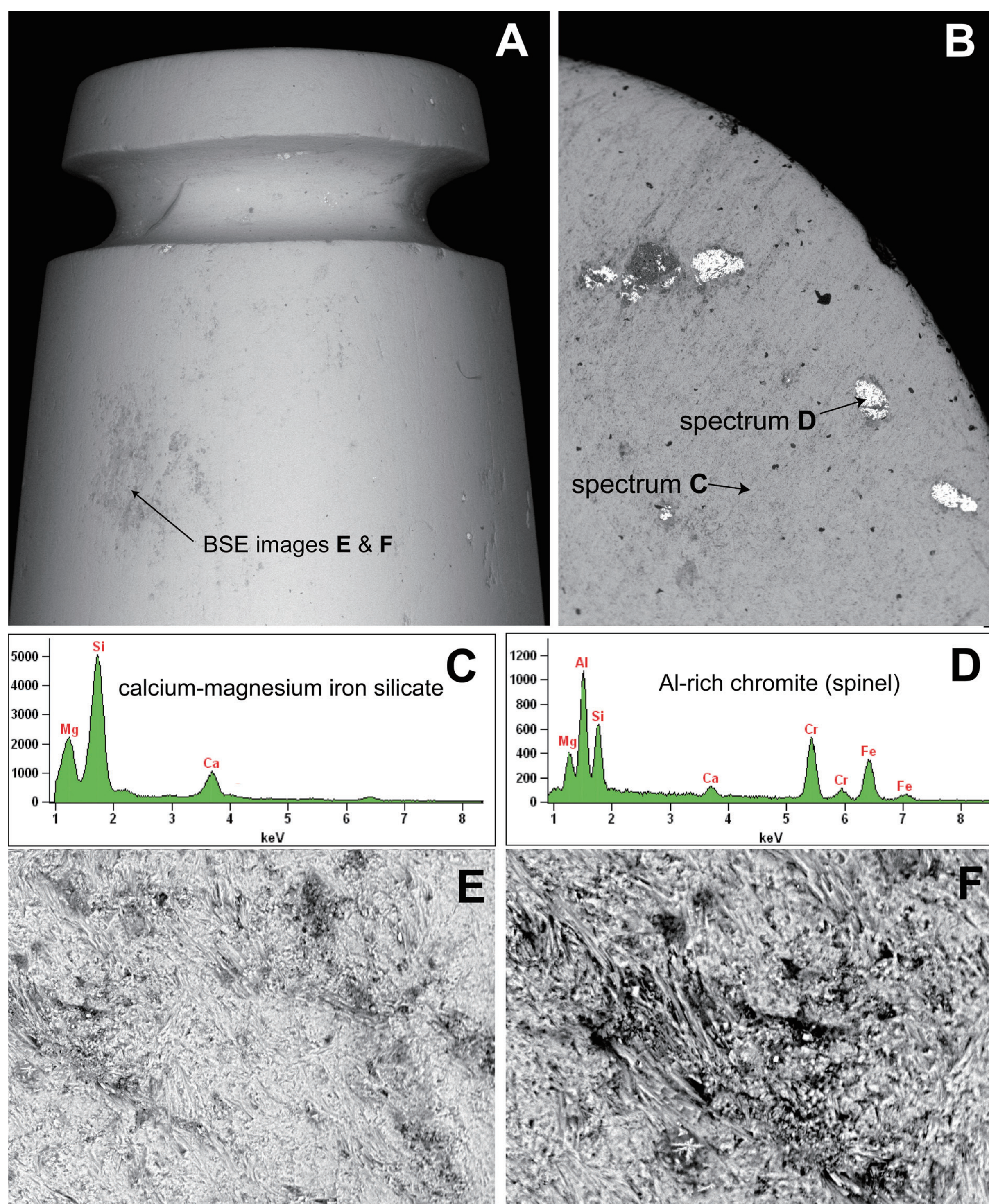
variations in their chemistry can sometimes even be used differentiate sources of the stone (Iizuka *et al.* 2005).

### Conclusion

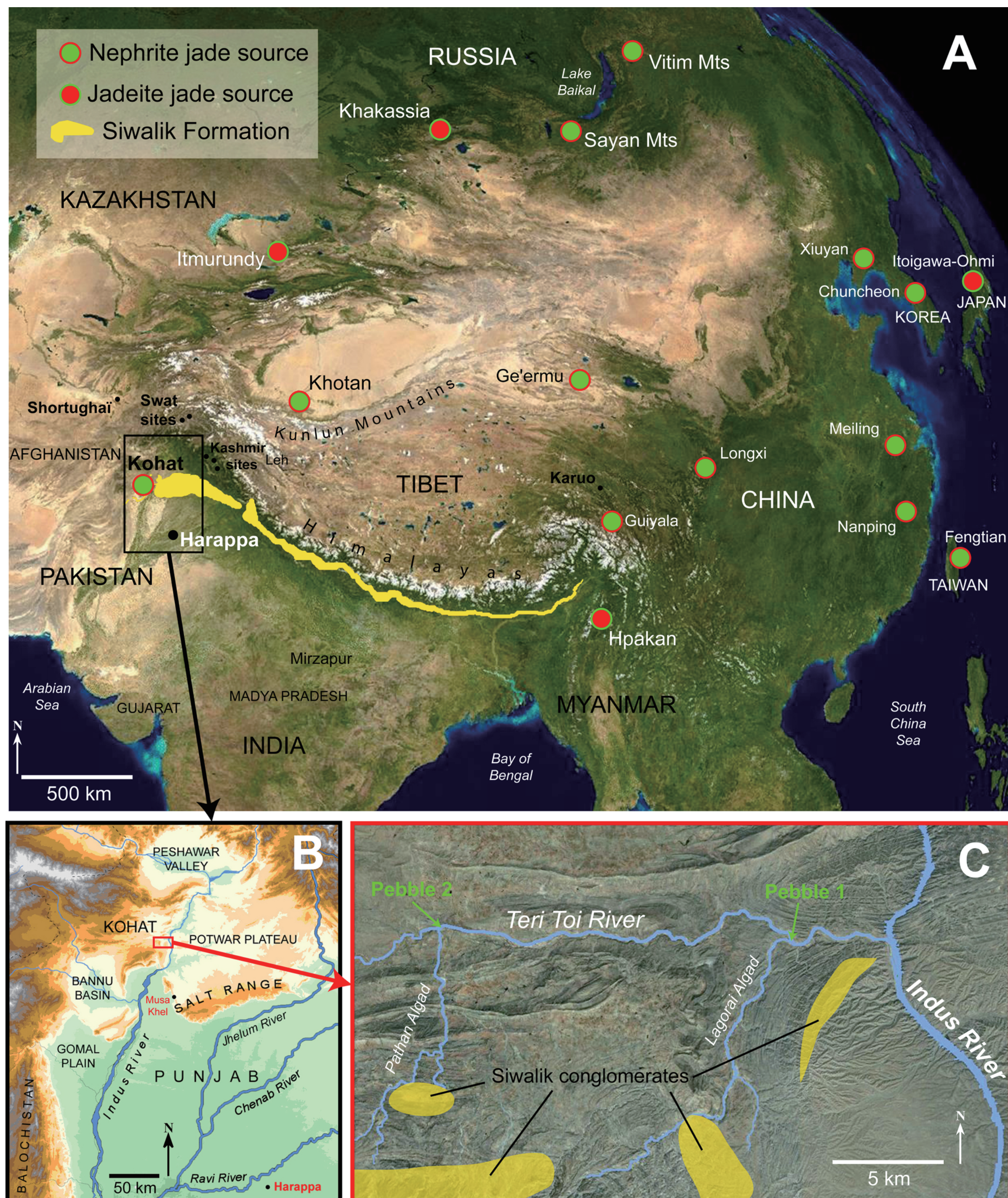
The semi-translucent, spinach-green colored truncated conical amulet recovered in the cemetery area at Harappa is almost certainly composed of nephrite jade. The macroscopic appearance, density, mineralogy, and microscopic texture of the stone from which the ornament is made are all consistent with that identification. This makes the amulet the first and, thus far, only positively confirmed jade artifact at an Indus Civilization site. The question now is – from what source did Harappans acquire this stone?

## POTENTIAL SOURCES

Jade is found in many locations across Asia




**Appendix 4.7 Figure 3** VP-SEM/EDS analysis of the amulet. **[A]** BSE images of the upper portion of the amulet showing the unpolished locations (points E & F) where detailed BSE images were made. **[B]** BSE image of the top surface of the amulet showing the black inclusions (which are white in the image) and locations (points C & D) where EDS scans were made. **[C]** EDS spectrum of the amulet's main phase. **[D]** EDS spectrum of the amulet's black inclusions. **[E & F]** BSE details of an unpolished area on the amulet where the fibrous texture of the natural stone is unobscured.




**Appendix 4.7 Figure 4** **[A]** Map of the Asian jade sources, archaeological sites and geologic formations discussed in this section. **[B]** Map of the upper Indus Valley Region. **[C]** The Teri Toi River area, Kohat with the locations where B.C.M Butler collected nephrite pebbles noted and the approximately locations of the Siwalik conglomerates highlighted (after Butler 1963a: Figure 5).

(Appendix 4.7 Figure 4 A). Although several occurrences have been reported within the Indian Subcontinent, nearly all of those either have been demonstrated to not actually exist or remain to be positively confirmed. Krishnaswamy stated (1979: 499) that jade could be found in Tamil Nadu, Madhya Pradesh and Gujarat. An examination of his primary source material, however, suggests that these are not actually sources of either jadeite or nephrite. For example, he cites C.S. Middlemiss (1921: 69)



**Appendix 4.7 Figure 5** Nephrite jade cobbles for sale in the Khotan bazaar, July 1997.

who described two types of material in northeast Gujarat (a translucent white pyroxene and a pale green tremolite-amphibole) that, when polished, were very "handsome" and "jade-like." Middlemiss even suggested that they might make good ornamental stone. He also, however, made it clear that neither material was dense enough to qualify as true jade. F.R. Mallet reported jade (presumably nephrite) in the Mirzapur area of what is today the state of Madhya Pradesh (Mallet 1872: 22) but this was later shown by K.P. Sinor (1923) to have been a misidentification. Somewhat more recently, Singh and Gupta reported (1987) jadeite pods within the ultramafic rocks of the Shyok Ophiolite, Leh District, Jammu and Kashmir. A more detailed mineralogical analysis is needed to confirm that the material from that locality is genuine jade, however.

The only positive identification of jade in South Asia thus far was made by geologist B.C.M. Butler of Oxford University (Butler 1963a, 1963b). He collected two pebbles from the bed of the Teri Toi river in the Kohat District, NWFP, which lies some 320 km north-northwest of Harappa (Appendix 4.7 Figure 4 B & C). Using a combination of thin-section petrography and XRD, Butler determined that both were composed of nephrite jade. He believed (but was not able to confirm) that the pebbles had to have eroded from nearby conglomerate beds of the Middle to Upper Siwaliks as there were no *in situ* metamorphic formations in the area from which they could have originated (Butler 1963a: 389-390). If he was correct, then it is conceivable that nephrite,

although perhaps rare, might be found at various other points across the extensive Siwalik Formation (highlighted in yellow on Appendix 4.7 Figure 4 A) where conglomerates containing metamorphic clasts also occur (Brozović and Burbank 2000; Cheema *et al*. 1977: 89-98). Most significantly in terms of the present study, Butler recorded (1963a: 387-389) that the larger of the nephrite pebbles had a translucent "spinach-green" appearance and tiny black inclusions of spinel – exactly like that of the Harappan amulet! The description of the smaller pebble – "pale greenish-white" (ibid.: 386), is somewhat reminiscent of the light-green colored jade beads and pendants recovered to the north of Kohat from the prehistoric sites of Ghalegay and Loebanr in the Swat Valley of the NWFP (Stacul 1987: 75). Still, it is possible that those ornaments, as well at the amulet from Harappa, are made from nephrite jade derived from a different source altogether.

Elsewhere across Asia, nephrite occurs near Lake Baikal, Russia in both the Sayan Mountains and the Vitim Mountains (Kolesnik 1970; O'Donoghue 2006: 341); it has been reported in Oman in the Bawshir – al-Khuwair area (el-Shazly and al-Belushi 2004), at Wadi al-Ain (Thesiger 1948: 14) and at Fanja, Wadi Hatta and Semail (Guba 2007: 320); the source at Chuncheon, South Korea is one of the largest in the world (Yui and Kwon 2002); material from the Fengtian deposit of eastern Taiwan has been traded across southeast Asia for 3000 years (Hung *et al*. 2007); in China, deposits of genuine nephrite have been documented at Xiuyan in Liaoning Province (Wang *et al*. 2002), at Longxi in Sichuan Province (Wang *et al*. 1990), at Meiling in Jiangsu Province (Zhong 1995), at Nanping in Fujian Province (Tang *et al*. 1997), at Ge'ermu in Qinghai Province (Kong *et al*. 1997), and in the Guiyala area of the Tibet Autonomous Region (Chen 1999). The most extensive nephrite jade source area in China – and the most pertinent with regard to the current study – is in the vicinity of Khotan (Hetian) in Xinjiang Province. Nearly 20 individual occurrences have been documented to south of that city across the Kunlun Mountain Range (for a map of these locations see Liu *et al* 2010: Figure 1 a). Jade from this region was being exploited since at least since the Neolithic Period (Bai and Wu 2002) and it still today fills the bazaars of the region (Appendix 4.7 Figure 5).

After Kohat, the deposits of the Khotan area are the nephrite occurrences nearest to Harappa. Although "near" in this case means over 900 km to the north-northwest across the highest mountains on earth, the existence of the Indus Civilization outpost of Shortughaï in northern Afghanistan (Francfort 1984b) amply demonstrates that Harappans had the ability to travel to regions beyond the high ranges of northwestern South Asia when they so desired. On the other hand, the acquisition of Khotan nephrite (if that is what the amulet is composed of) could have been indirect and carried out through trade with the non-Harappa peoples inhabiting northern highland regions such as Swat and Kashmir. These so-called "Northern Neolithic" groups had clear affinities with the cultures of Inner and East Asia (Fairservis 1975: 312-318; Stacul 1994) and, in some instances (Stacul 1987: 75), used jade themselves. One site that exhibits strong material culture parallels with those groups is Karuo in eastern Tibet (Xu 1991). Indirect, long-distance interaction with the inhabitants of that settlement and others like it could conceivably have provided Harappans access to jade from eastern Tibet or even China.

Despite of the existence of many potential jade sources and evidence for links across the Tibetan Plateau, I feel that the Kohat nephrite occurrence is the most likely source of the raw material used to fashion the nephrite amulet from Harappa. Indus Civilization peoples were dwelling a mere 75 km south of the Teri Toi River at Musa Khel and the Indus River, which would have been and important transitway between the Punjab Plain and the northern reaches of the Subcontinent, passes almost directly

adjacent to the source. Most importantly, the amulet is macroscopically and mineralogically comparable to one of the nephrite pebbles B.C.M. Butler collected there. Additional geologic samples will need to be acquired and further analytical studies will need to be undertaken in order to confirm that Teri Toi area of Kohat was indeed the source, however.

## POSSIBILITIES FOR FUTURE STUDIES

The nephrite amulet from Harappa is a complete, one-of-a-kind artifact and, therefore, any future provenience studies will have to involve non-descructive or, at least, minimally invasive methods. Utilizing both proton induced X-ray emission (PIXE) and laser raman spectroscopy (LRS), Gan and others (2008) were able to determine that jades from the Shang Dynasty site of Yinxu probably were not derived from the Hetain source area. Using a VP-SEM coupled with an EDS to examine the composition of spinel-chromite inclusions, Iizuka and others (2005) determined that nephrite artifacts excavated at a site in the Philippines were analogous to jade from the Fengtian sources in Taiwan. Casadio and others (2007) employed a suite of non-invasive methods (Raman microspectroscopy, visible reflectance spectroscopy and XRD) to characterize jade artifacts and experimental samples. Much of the data they collected are useful for provenience studies.

If nephrite manufacturing debris or broken artifacts that can be sampled are eventually recovered at Harappa then, perhaps, provenience analyses could be undertaken using successfully employed invasive methods such as ICP-MS (Chen *et al* 2000), EMPA (Iizuka and Hung 2005), argon isotope (Ar-Ar) dating (Chou *et al*. 2009) and strontium isotope analysis (Adams *et al*. 2007). Current research indicates that nephrite deposits form due to the metamorphic or metasomatic alteration of either serpentinite or dolomitic marble (Harlow and Sorensen 2005; Lui *et al*. 2010: 249-250). Thus, like I show for steatite in Chapter 7 of this book, it should be possible to determine, using any of variety of techniques, which type of deposit an artifact comes from by examining the abundances of elements in it such as Ni, Cr, Fe and Mn. In this way certain deposits could be ruled out as potential sources.

# APPENDIX 5.1

# ALL QUERNS AND MULLERS (WHOLE AND FRAGMENTARY) RECOVERED FROM EXCAVATIONS AND SURVEYS AT HARAPPA FROM 1986 TO 2004

In the tables below each artifact is first listed by year, lot and record number.

The location from which an artifact was recovered is noted by mound (AB, E, ET, F or LW [low western]), operation (Op.), area (CEM = cemetery, MS = Mughal Sarai) or trench number (for certain off-mound trenches).

An artifact's context is noted by period number (1, 2, 3A, 3B, 3C, 4 or 5) if it was recovered from secure deposits. Context is noted as "S&D" if it came from either surface or disturbed deposits. In rare instances (such as miscellaneous finds turned in by workmen) an artifact's context is not available (n/a).

Designated material type is listed as Pab sandstone (PAB), Delhi quartzite (DQ), Kirana Hills stone (KH) gray sandstone (GSS) or unknown (UNK).

The weight of each artifact is provided in grams.

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 86 | 0.002 | 27 | E | S&D | GSS | 290 |
| 86 | 0.004 | 37 | E | S&D | DQ | 338 |
| 86 | 0.004 | 38 | E | S&D | GSS | 174 |
| 86 | 0.005 | 96 | E | S&D | PAB | 462 |
| 86 | 0.006 | 58 | E | S&D | DQ | 72 |
| 86 | 0.006 | 57 | E | S&D | UNK | 247 |
| 86 | 0.024 | 216 | E | S&D | DQ | 143 |
| 86 | 0.024 | 218 | E | S&D | DQ | 1000 |
| 86 | 0.024 | 213 | E | S&D | GSS | 434 |
| 86 | 0.024 | 214 | E | S&D | PAB | 283 |
| 86 | 0.024 | 215 | E | S&D | PAB | 228 |
| 86 | 0.024 | 219 | E | S&D | PAB | 133 |
| 86 | 0.029 | 10 | LW | S&D | PAB | 685 |
| 86 | 0.033 | 16 | E | S&D | UNK | 67 |
| 86 | 0.042 | 63 | E | S&D | DQ | 8 |
| 86 | 0.042 | 64 | E | S&D | DQ | 6 |
| 86 | 0.042 | 66 | E | S&D | DQ | 5 |
| 86 | 0.042 | 67 | E | S&D | DQ | 3 |
| 86 | 0.042 | 65 | E | S&D | PAB | 6 |
| 86 | 0.043 | 42 | E | S&D | GSS | 242 |
| 86 | 0.043 | 41 | E | S&D | UNK | 327 |
| 86 | 0.043 | 44 | E | S&D | UNK | 132 |
| 86 | 0.047 | 21 | E | S&D | DQ | 19 |
| 86 | 0.047 | 22 | E | S&D | DQ | 14 |
| 88 | 329 | 6 | E | 3C | UNK | 38 |
| 88 | 330 | 3 | E | S&D | PAB | 832 |
| 88 | 334 | 9 | E | S&D | PAB | 208.7 |
| 88 | 340 | 9 | E | 3C | PAB | 33.7 |
| 88 | 343 | 41 | E | S&D | DQ | 765 |
| 88 | 343 | 63 | E | S&D | PAB | 365.5 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 86 | 0.047 | 23 | E | S&D | DQ | 6 |
| 86 | 0.126 | 27 | AB | S&D | PAB | 77 |
| 86 | 0.126 | 28 | AB | S&D | UNK | 57 |
| 87 | 3 | 31 | CEM | S&D | UNK | 126 |
| 87 | 11 | 21 | CEM | 3C | GSS | 330 |
| 87 | 33 | 2 | CEM | 3C | UNK | 435 |
| 87 | 50 | 1 | CEM | 3C | UNK | 236.2 |
| 87 | 62 | 68 | CEM | 3C | DQ | 164 |
| 87 | 73 | 22 | CEM | 3C | PAB | 124 |
| 87 | 127 | 8 | CEM | 3C | GSS | 173 |
| 87 | 130 | 1 | CEM | 3C | UNK | 287 |
| 87 | 141 | 4 | CEM | 3C | UNK | 179 |
| 87 | 144 | 1 | CEM | 3B | UNK | 72 |
| 88 | 210 | 1 | CEM | S&D | UNK | 254.8 |
| 88 | 241 | 5 | CEM | S&D | DQ | 127.6 |
| 87 | 300 | 10 | n/a | n/a | PAB | 139.7 |
| 87 | 303 | 11 | E | 3C | GSS | 255 |
| 87 | 303 | 12 | E | 3C | PAB | 290 |
| 88 | 321 | 15 | E | S&D | PAB | 211 |
| 88 | 321 | 2 | E | S&D | UNK | 93.5 |
| 88 | 321 | 14 | E | S&D | UNK | 132.5 |
| 88 | 322 | 6 | E | S&D | UNK | 1490 |
| 88 | 324 | 2 | E | 3C | GSS | 177.3 |
| 88 | 326 | 16 | E | 3C | PAB | 649.7 |
| 87 | 518 | 50 | AB | S&D | GSS | 677 |
| 87 | 518 | 47 | AB | S&D | PAB | 187 |
| 87 | 518 | 48 | AB | S&D | PAB | 354 |
| 87 | 518 | 49 | AB | S&D | UNK | 434 |
| 87 | 525 | 51 | AB | S&D | UNK | 927 |
| 87 | 525 | 108 | AB | S&D | DQ | 74.5 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 88 | 343 | 64 | E | S&D | PAB | 68 |
| 88 | 343 | 65 | E | S&D | UNK | 158 |
| 88 | 344 | 96 | E | 3C | GSS | 75.5 |
| 88 | 348 | 12 | E | 3C | DQ | 3200 |
| 88 | 348 | 2 | E | 3C | PAB | 293.5 |
| 88 | 348 | 17 | E | 3C | PAB | 124 |
| 88 | 348 | 20 | E | 3C | UNK | 248.9 |
| 88 | 348 | 28 | E | 3C | UNK | 248 |
| 88 | 353 | 17 | E | 3C | PAB | 3200 |
| 88 | 354 | 66 | E | 3C | PAB | 113.5 |
| 88 | 355 | 48 | E | 3C | UNK | 192.5 |
| 88 | 358 | 12 | E | 3C | PAB | 750 |
| 88 | 363 | 11 | E | S&D | UNK | 65 |
| 88 | 365 | 11 | E | S&D | DQ | 1074 |
| 88 | 365 | 11 | E | S&D | DQ | 1074 |
| 88 | 365 | 10 | E | S&D | PAB | 1450 |
| 88 | 433 | 1 | CEM | 3C | PAB | 36 |
| 88 | 433 | 20 | CEM | 3C | UNK | 57.5 |
| 88 | 436 | 7 | CEM | 3C | UNK | 120.5 |
| 88 | 436 | 37 | CEM | 3C | UNK | 29 |
| 87 | 501 | 2 | AB | S&D | UNK | 97.5 |
| 87 | 502 | 5 | AB | S&D | UNK | 89 |
| 87 | 503 | 23b | AB | S&D | PAB | 400 |
| 87 | 503 | 23 | AB | S&D | UNK | 235.8 |
| 87 | 505 | 49 | AB | S&D | PAB | 336 |
| 87 | 508 | 21 | AB | 3C | DQ | 53.5 |
| 87 | 508 | 23 | AB | 3C | DQ | 346.6 |
| 87 | 508 | 20 | AB | 3C | PAB | 698 |
| 87 | 513 | 4 | AB | S&D | GSS | 151.1 |
| 87 | 514 | 22 | AB | 3C | DQ | 204 |
| 87 | 514 | 11 | AB | 3C | GSS | 572 |
| 87 | 514 | 10 | AB | 3C | UNK | 524.5 |
| 87 | 514 | 11 | AB | 3C | UNK | 104.3 |
| 87 | 515 | 13 | AB | S&D | GSS | 1146 |
| 87 | 516 | 13 | AB | S&D | DQ | 166.7 |
| 87 | 516 | 20 | AB | S&D | GSS | 326.7 |
| 87 | 516 | 14 | AB | S&D | UNK | 393 |
| 87 | 518 | 15 | AB | S&D | GSS | 319.8 |
| 87 | 518 | 38 | AB | S&D | GSS | 220 |
| 88 | 734 | 4 | E | 3C | PAB | 733.5 |
| 88 | 746 | 7 | E | S&D | PAB | 302.5 |
| 88 | 752 | 3 | E | 3C | PAB | 385 |
| 88 | 767 | 34 | E | 3B | UNK | 36.2 |
| 88 | 767 | 35 | E | 3B | UNK | 36.1 |
| 88 | 769 | 1 | E | 3B | PAB | 359 |
| 88 | 781 | 2 | E | 3B | PAB | 426.5 |
| 88 | 783 | 29 | E | 3B | UNK | 310 |
| 88 | 797 | 36 | E | 3A | GSS | 227 |
| 88 | 802 | 52 | E | 3C | PAB | 25 |
| 88 | 802 | 53 | E | 3C | PAB | 24 |
| 88 | 1000 | 5 | E | 3A | UNK | 74.5 |
| 89 | 1013 | 9 | E | S&D | KH | 351 |
| 89 | 1015 | 21 | Op.6 | S&D | UNK | 156 |
| 89 | 1015 | 22 | Op.6 | S&D | UNK | 152 |
| 89 | 1018 | 15 | Op.6 | S&D | PAB | 590 |
| 89 | 1024 | 18 | E | 3A | UNK | 296.4 |
| 89 | 1027 | 29 | Op.6 | S&D | PAB | 118 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 87 | 525 | 161 | AB | S&D | PAB | 997 |
| 87 | 525 | 162 | AB | S&D | PAB | 374.5 |
| 87 | 525 | 163 | AB | S&D | PAB | 105 |
| 87 | 525 | 164 | AB | S&D | UNK | 114 |
| 87 | 525 | 165 | AB | S&D | PAB | 677 |
| 87 | 525 | 166 | AB | S&D | UNK | 22.7 |
| 87 | 525 | 167 | AB | S&D | UNK | 35.7 |
| 87 | 525 | 168 | AB | S&D | PAB | 73.5 |
| 87 | 525 | 175 | AB | S&D | UNK | 394.5 |
| 88 | 528 | 37 | AB | S&D | PAB | 116.9 |
| 88 | 528 | 57 | AB | S&D | PAB | 167 |
| 88 | 528 | 56 | AB | S&D | UNK | 92 |
| 88 | 538 | 6 | AB | 3C | PAB | 170.5 |
| 88 | 540 | 3 | AB | 3C | PAB | 465 |
| 88 | 546 | 2 | AB | 3C | UNK | 145.5 |
| 88 | 553 | 3 | AB | 3C | PAB | 454 |
| 88 | 559 | 21 | AB | 3C | UNK | 432 |
| 88 | 572 | 21 | AB | 3C | PAB | 120 |
| 89 | 586 | 10 | AB | 3C | PAB | 294 |
| 94 | 634 | 1 | AB | S&D | KH | 118.3 |
| 94 | 645 | 10 | AB | S&D | PAB | 995 |
| 94 | 651 | 1 | AB | S&D | PAB | 400 |
| 94 | 658 | 1 | AB | S&D | PAB | 228 |
| 94 | 699 | 8 | AB | S&D | DQ | 9.3 |
| 94 | 699 | 1 | AB | S&D | KH | 173.3 |
| 88 | 700 | 36 | E | S&D | PAB | 356 |
| 88 | 703 | 7 | E | 3C | UNK | 101.8 |
| 88 | 703 | 15 | E | 3C | UNK | 178 |
| 88 | 709 | 36 | E | S&D | PAB | 356 |
| 88 | 712 | 1 | E | S&D | UNK | 134 |
| 88 | 714 | 17 | E | S&D | DQ | 385 |
| 88 | 714 | 25 | E | S&D | DQ | 464 |
| 88 | 725 | 75 | E | 3C | PAB | 391.5 |
| 88 | 725 | 77 | E | 3C | PAB | 512.5 |
| 88 | 725 | 82 | E | 3C | PAB | 324 |
| 88 | 725 | 86 | E | 3C | PAB | 458.2 |
| 88 | 725 | 125 | E | 3C | PAB | 6500 |
| 88 | 725 | 128 | E | 3C | PAB | 7 |
| 88 | 731 | 8 | E | S&D | PAB | 370.5 |
| 89 | 1115 | 5 | E | 3A | GSS | 147 |
| 89 | 1115 | 6 | E | 3A | KH | 322 |
| 89 | 1120 | 11 | E | S&D | KH | 305 |
| 89 | 1121 | 31 | E | S&D | KH | 27.5 |
| 89 | 1121 | 32 | E | S&D | PAB | 33.2 |
| 89 | 1121 | 13 | E | S&D | UNK | 57.7 |
| 89 | 1124 | 7 | E | 2 | KH | 72.8 |
| 89 | 1135 | 1 | E | 2 | UNK | 86.9 |
| 89 | 1136 | 1 | E | 2 | KH | 62.5 |
| 90 | 1142 | 15 | E | S&D | UNK | 613 |
| 90 | 1147 | 4 | E | 3A | UNK | 60.8 |
| 90 | 1147 | 20 | E | 3A | UNK | 234 |
| 90 | 1150 | 18 | E | 2 | PAB | 30 |
| 90 | 1150 | 19 | E | 2 | PAB | 124 |
| 90 | 1152 | 29 | E | 3A | KH | 187.7 |
| 90 | 1153 | 42 | E | S&D | KH | 160.7 |
| 90 | 1156 | 74 | E | 2 | KH | 185.6 |
| 90 | 1156 | 75 | E | 2 | KH | 134.6 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 89 | 1038 | 25 | Op.6 | S&D | DQ | 186 |
| 89 | 1038 | 24 | Op.6 | S&D | PAB | 128 |
| 89 | 1046 | 30 | E | 2 | KH | 30.6 |
| 89 | 1046 | 31 | E | 2 | KH | 39.4 |
| 89 | 1054 | 130 | E | S&D | KH | 63.6 |
| 89 | 1056 | 13 | E | 2 | DQ | 43.1 |
| 89 | 1056 | 2 | E | 2 | UNK | 102.8 |
| 89 | 1060 | 112 | E | S&D | KH | 198.7 |
| 89 | 1060 | 113 | E | S&D | KH | 839 |
| 89 | 1060 | 110 | E | S&D | UNK | 78.1 |
| 89 | 1060 | 111 | E | S&D | UNK | 215.3 |
| 89 | 1067 | 85 | E | S&D | KH | 114 |
| 89 | 1067 | 35 | E | S&D | PAB | 151 |
| 89 | 1067 | 34 | E | S&D | UNK | 130.4 |
| 89 | 1072 | 11 | Op.6 | S&D | UNK | 28.3 |
| 89 | 1075 | 22 | E | S&D | GSS | 163 |
| 89 | 1075 | 21 | E | S&D | UNK | 244.4 |
| 89 | 1078 | 8 | E | S&D | GSS | 126.4 |
| 89 | 1083 | 31 | E | S&D | KH | 157 |
| 89 | 1084 | 6 | Op.6 | S&D | PAB | 154 |
| 89 | 1087 | 3 | E | S&D | UNK | 87.4 |
| 89 | 1091 | 13 | E | S&D | PAB | 109 |
| 89 | 1101 | 4 | E | 3A | KH | 249 |
| 89 | 1104 | 4 | E | S&D | UNK | 159 |
| 89 | 1105 | 9 | E | S&D | KH | 320 |
| 89 | 1107 | 13 | E | S&D | PAB | 502 |
| 89 | 1110 | 4 | E | S&D | UNK | 747 |
| 90 | 1187 | 20 | E | 2 | KH | 48.7 |
| 90 | 1187 | 21 | E | 2 | KH | 157.5 |
| 90 | 1187 | 22 | E | 2 | UNK | 260 |
| 90 | 1189 | 7 | E | 2 | UNK | 99.9 |
| 90 | 1191 | 13 | E | 2 | KH | 52.7 |
| 90 | 1191 | 14 | E | 2 | KH | 37.8 |
| 90 | 1191 | 15 | E | 2 | KH | 14.9 |
| 90 | 1191 | 16 | E | 2 | KH | 4.8 |
| 90 | 1191 | 17 | E | 2 | KH | 65.8 |
| 90 | 1191 | 18 | E | 2 | KH | 39.4 |
| 90 | 1191 | 20 | E | 2 | KH | 339 |
| 90 | 1191 | 25 | E | 2 | KH | 21.2 |
| 90 | 1191 | 28 | E | 2 | KH | 85.8 |
| 90 | 1191 | 19 | E | 2 | UNK | 180.2 |
| 90 | 1197 | 11 | E | 2 | KH | 79.6 |
| 90 | 1197 | 12 | E | 2 | KH | 159.3 |
| 90 | 1197 | 17 | E | 2 | KH | 40.4 |
| 90 | 1198 | 16 | E | 2 | KH | 80.5 |
| 90 | 1198 | 19 | E | 2 | KH | 12.2 |
| 90 | 1200 | 40 | E | 2 | KH | 79.9 |
| 90 | 1200 | 41 | E | 2 | KH | 326 |
| 90 | 1200 | 42 | E | 2 | KH | 49.6 |
| 90 | 1200 | 43 | E | 2 | KH | 252 |
| 90 | 1200 | 44 | E | 2 | KH | 152.3 |
| 90 | 1200 | 45 | E | 2 | KH | 95.3 |
| 90 | 1200 | 76 | E | 2 | KH | 20.4 |
| 90 | 1200 | 77 | E | 2 | KH | 5.9 |
| 90 | 1200 | 12 | E | 2 | UNK | 181.4 |
| 90 | 1207 | 9 | E | 2 | KH | 80.2 |
| 90 | 1207 | 8 | E | 2 | UNK | 89.6 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 90 | 1157 | 75 | E | S&D | PAB | 19.3 |
| 90 | 1157 | 1 | E | S&D | SR | 347.7 |
| 90 | 1157 | 67 | E | S&D | UNK | 6.6 |
| 90 | 1163 | 1 | E | 2 | UNK | 607.5 |
| 90 | 1164 | 21 | E | 2 | KH | 135.8 |
| 90 | 1170 | 32 | E | 2 | KH | 457.5 |
| 90 | 1170 | 34 | E | 2 | KH | 90.6 |
| 90 | 1174 | 16 | E | 2 | KH | 203 |
| 90 | 1174 | 17 | E | 2 | KH | 209 |
| 90 | 1175 | 25 | E | 2 | KH | 20.8 |
| 90 | 1175 | 25 | E | 2 | KH | 26.2 |
| 90 | 1175 | 26 | E | 2 | KH | 89 |
| 90 | 1175 | 31 | E | 2 | KH | 211.9 |
| 90 | 1177 | 5 | E | 2 | KH | 506 |
| 90 | 1177 | 6 | E | 2 | KH | 210.2 |
| 90 | 1178 | 28 | E | 3A | KH | 54.1 |
| 90 | 1180 | 15 | E | 2 | KH | 42.8 |
| 90 | 1180 | 16 | E | 2 | KH | 64.4 |
| 90 | 1181 | 16 | E | 2 | KH | 141.6 |
| 90 | 1181 | 17 | E | 2 | KH | 144.7 |
| 90 | 1181 | 28 | E | 2 | KH | 76.4 |
| 90 | 1182 | 82 | E | 2 | KH | 28.5 |
| 90 | 1183 | 4 | E | 2 | KH | 113.4 |
| 90 | 1187 | 16 | E | 2 | KH | 25 |
| 90 | 1187 | 17 | E | 2 | KH | 50 |
| 90 | 1187 | 18 | E | 2 | KH | 70.6 |
| 90 | 1187 | 19 | E | 2 | KH | 59.2 |
| 90 | 1302 | 4 | E | 2 | KH | 12 |
| 90 | 1303 | 18 | E | 2 | UNK | 34.5 |
| 89 | 2000 | 65 | E | S&D | PAB | 904 |
| 89 | 2000 | 66 | E | S&D | UNK | 112.5 |
| 89 | 2005 | 16 | E | 3A | UNK | 8.3 |
| 89 | 2005 | 65 | E | 3A | UNK | 63.8 |
| 89 | 2006 | 134 | E | S&D | UNK | 599 |
| 89 | 2014 | 4 | E | 3B | PAB | 35.6 |
| 89 | 2033 | 5 | E | 3B | PAB | 92.1 |
| 89 | 2047 | 1 | E | 3A | KH | 162 |
| 89 | 2052 | 9 | E | 3B | UNK | 247.4 |
| 90 | 2071 | 9 | E | S&D | KH | 39 |
| 2000 | 2087 | 7 | E | S&D | PAB | 251 |
| 2000 | 2101 | 60 | E | S&D | UNK | 59 |
| 2000 | 2102 | 310 | E | S&D | DQ | 50 |
| 2000 | 2102 | 928 | E | S&D | DQ | 80.8 |
| 2000 | 2102 | 1561 | E | S&D | DQ | 146.6 |
| 2000 | 2102 | 905 | E | S&D | PAB | 500 |
| 2000 | 2102 | 906 | E | S&D | PAB | 953 |
| 2000 | 2102 | 1558 | E | S&D | PAB | 42.5 |
| 2000 | 2102 | 1559 | E | S&D | PAB | 85.3 |
| 2000 | 2102 | 1562 | E | S&D | PAB | 126.6 |
| 2000 | 2102 | 904 | E | S&D | UNK | 374 |
| 2000 | 2102 | 926 | E | S&D | UNK | 54.7 |
| 2000 | 2102 | 1560 | E | S&D | UNK | 90.6 |
| 2000 | 2104 | 138 | E | S&D | DQ | 153.2 |
| 2000 | 2104 | 93 | E | S&D | PAB | 132 |
| 2000 | 2104 | 94 | E | S&D | PAB | 61.6 |
| 2000 | 2104 | 96 | E | S&D | PAB | 34.2 |
| 2000 | 2104 | 139 | E | S&D | PAB | 212.7 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 90 | 1210 | 6 | E | 2 | UNK | 6.3 |
| 90 | 1215 | 40 | E | 2 | KH | 4.3 |
| 90 | 1216 | 38 | E | 2 | UNK | 4.8 |
| 90 | 1218 | 16 | E | 2 | UNK | 26.7 |
| 90 | 1223 | 6 | E | 2 | KH | 153 |
| 90 | 1223 | 1 | E | 2 | KH | 200 |
| 90 | 1224 | 6 | E | 2 | KH | 98 |
| 90 | 1228 | 3 | E | 2 | KH | 1.5 |
| 90 | 1228 | 4 | E | 2 | KH | 0.9 |
| 90 | 1232 | 4 | E | 2 | KH | 193.7 |
| 90 | 1232 | 6 | E | 2 | KH | 4.6 |
| 90 | 1234 | 1 | E | 2 | KH | 18.3 |
| 90 | 1235 | 1 | E | 2 | KH | 1 |
| 90 | 1260 | 33 | E | S&D | KH | 102 |
| 90 | 1260 | 34 | E | S&D | UNK | 219 |
| 2000 | 2110 | 328 | E | S&D | UNK | 252 |
| 2000 | 2111 | 73 | E | S&D | UNK | 227.8 |
| 2000 | 2112 | 66 | E | S&D | DQ | 39.4 |
| 2000 | 2112 | 64 | E | S&D | KH | 284.9 |
| 2000 | 2112 | 67 | E | S&D | KH | 36.6 |
| 2000 | 2112 | 65 | E | S&D | PAB | 129.2 |
| 2000 | 2113 | 54 | E | S&D | UNK | 103.7 |
| 2000 | 2114 | 63 | E | S&D | PAB | 217.1 |
| 2000 | 2114 | 78 | E | S&D | UNK | 14.2 |
| 2000 | 2115 | 48 | E | S&D | PAB | 219.8 |
| 2000 | 2115 | 49 | E | S&D | PAB | 280 |
| 2000 | 2115 | 70 | E | S&D | PAB | 392 |
| 2000 | 2121 | 110 | E | S&D | DQ | 148.5 |
| 2000 | 2121 | 198 | E | S&D | DQ | 202 |
| 2000 | 2121 | 108 | E | S&D | PAB | 1302 |
| 2000 | 2121 | 109 | E | S&D | PAB | 258.8 |
| 2000 | 2121 | 111 | E | S&D | PAB | 74.8 |
| 2000 | 2121 | 112 | E | S&D | PAB | 475 |
| 2000 | 2121 | 113 | E | S&D | PAB | 145.9 |
| 2000 | 2121 | 114 | E | S&D | PAB | 213 |
| 2000 | 2121 | 115 | E | S&D | PAB | 234.7 |
| 2000 | 2121 | 116 | E | S&D | PAB | 188.1 |
| 2000 | 2121 | 117 | E | S&D | PAB | 974 |
| 2000 | 2121 | 118 | E | S&D | UNK | 363 |
| 2000 | 2123 | 16 | E | S&D | KH | 617 |
| 2000 | 2123 | 33 | E | S&D | PAB | 107.3 |
| 2000 | 2123 | 17 | E | S&D | UNK | 682 |
| 2000 | 2133 | 1 | E | S&D | PAB | 140.2 |
| 2000 | 2133 | 27 | E | S&D | UNK | 16.3 |
| 2000 | 2133 | 28 | E | S&D | UNK | 3.6 |
| 2000 | 2139 | 147 | E | S&D | DQ | 20.3 |
| 2000 | 2139 | 149 | E | S&D | DQ | 18.1 |
| 2000 | 2139 | 143 | E | S&D | PAB | 2021.9.5 |
| 2000 | 2139 | 145 | E | S&D | PAB | 83.2 |
| 2000 | 2139 | 151 | E | S&D | PAB | 388 |
| 2000 | 2139 | 152 | E | S&D | PAB | 581 |
| 2000 | 2139 | 144 | E | S&D | UNK | 24.8 |
| 2000 | 2139 | 146 | E | S&D | UNK | 46.6 |
| 2000 | 2139 | 148 | E | S&D | UNK | 57.2 |
| 2000 | 2140 | 8 | E | 3A | PAB | 102.6 |
| 2000 | 2149 | 35 | E | S&D | PAB | 387 |
| 2000 | 2149 | 36 | E | S&D | UNK | 254.5 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 2000 | 2105 | 2 | E | S&D | DQ | 458 |
| 2000 | 2105 | 3 | E | S&D | PAB | 137.7 |
| 2000 | 2110 | 37 | E | S&D | DQ | 123 |
| 2000 | 2110 | 72 | E | S&D | DQ | 114.1 |
| 2000 | 2110 | 74 | E | S&D | DQ | 36.7 |
| 2000 | 2110 | 33 | E | S&D | PAB | 149 |
| 2000 | 2110 | 34 | E | S&D | PAB | 161.5 |
| 2000 | 2110 | 36 | E | S&D | PAB | 100.8 |
| 2000 | 2110 | 38 | E | S&D | PAB | 278 |
| 2000 | 2110 | 40 | E | S&D | PAB | 237.5 |
| 2000 | 2110 | 73 | E | S&D | PAB | 35.9 |
| 2000 | 2110 | 319 | E | S&D | PAB | 432 |
| 2000 | 2110 | 320 | E | S&D | PAB | 263 |
| 2000 | 2110 | 39 | E | S&D | UNK | 300 |
| 2000 | 2110 | 326 | E | S&D | UNK | 116.2 |
| 2000 | 2151 | 72 | E | S&D | PAB | 53.3 |
| 2000 | 2157 | 20 | E | 3B | UNK | 139.6 |
| 2000 | 2158 | 9 | E | 3B | KH | 96.7 |
| 2000 | 2165 | 35 | E | S&D | PAB | 104.3 |
| 2000 | 2165 | 36 | E | S&D | PAB | 98.2 |
| 2000 | 2165 | 37 | E | S&D | PAB | 130.1 |
| 2000 | 2174 | 315 | E | S&D | DQ | 121.5 |
| 2000 | 2174 | 319 | E | S&D | DQ | 787 |
| 2000 | 2174 | 317 | E | S&D | PAB | 1396 |
| 2000 | 2174 | 318 | E | S&D | PAB | 2006 |
| 2000 | 2174 | 320 | E | S&D | PAB | 549 |
| 2000 | 2174 | 854 | E | S&D | PAB | 170.1 |
| 2000 | 2174 | 911 | E | S&D | PAB | 1734 |
| 2000 | 2174 | 912 | E | S&D | PAB | 153.7 |
| 2000 | 2174 | 913 | E | S&D | PAB | 633 |
| 2000 | 2174 | 914 | E | S&D | PAB | 888 |
| 2000 | 2174 | 915 | E | S&D | PAB | 125.7 |
| 2000 | 2174 | 916 | E | S&D | PAB | 198.4 |
| 2000 | 2174 | 917 | E | S&D | PAB | 240.1 |
| 2000 | 2174 | 918 | E | S&D | PAB | 251 |
| 2000 | 2174 | 919 | E | S&D | PAB | 158.5 |
| 2000 | 2174 | 922 | E | S&D | PAB | 303 |
| 2000 | 2174 | 976 | E | S&D | PAB | 2445 |
| 2000 | 2174 | 977 | E | S&D | PAB | 2084 |
| 2000 | 2174 | 316 | E | S&D | UNK | 130.9 |
| 2000 | 2174 | 708 | E | S&D | UNK | 72.1 |
| 2000 | 2174 | 910 | E | S&D | UNK | 85.5 |
| 2000 | 2174 | 921 | E | S&D | UNK | 227.8 |
| 2000 | 2174 | 923 | E | S&D | UNK | 95.4 |
| 2000 | 2174 | 924 | E | S&D | UNK | 266.9 |
| 2000 | 2194 | 51 | E | S&D | UNK | 137 |
| 2000 | 2215 | 23 | E | S&D | PAB | 321 |
| 2000 | 2226 | 157 | E | S&D | DQ | 195.3 |
| 2000 | 2226 | 173 | E | S&D | DQ | 31.7 |
| 2000 | 2226 | 174 | E | S&D | PAB | 407 |
| 2000 | 2226 | 175 | E | S&D | PAB | 105.7 |
| 2000 | 2226 | 179 | E | S&D | PAB | 562 |
| 2000 | 2226 | 180 | E | S&D | PAB | 1906 |
| 2000 | 2226 | 177 | E | S&D | UNK | 40.2 |
| 2000 | 2226 | 178 | E | S&D | UNK | 233.1 |
| 2000 | 2227 | 66 | E | S&D | DQ | 32 |
| 2000 | 2227 | 64 | E | S&D | PAB | 136.7 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 2000 | 2150 | 1 | E | S&D | PAB | 195 |
| 2000 | 2151 | 70 | E | S&D | DQ | 11.2 |
| 2000 | 2151 | 71 | E | S&D | PAB | 64 |
| 2000 | 2227 | 377 | E | S&D | PAB | 117 |
| 2000 | 2227 | 63 | E | S&D | UNK | 3.7 |
| 2000 | 2227 | 375 | E | S&D | UNK | 72.8 |
| 2000 | 2229 | 23 | E | 3B | UNK | 42.6 |
| 2000 | 2232 | 1 | E | 3B | PAB | 130 |
| 2000 | 2235 | 1 | E | 3B | PAB | 152 |
| 2000 | 2312 | 30 | E | 3A | DQ | 278.5 |
| 2000 | 2312 | 31 | E | 3A | DQ | 34.9 |
| 2000 | 2338 | 8 | E | 3A | PAB | 326 |
| 2000 | 2358 | 28 | E | S&D | DQ | 12.4 |
| 2000 | 2358 | 29 | E | S&D | PAB | 15.3 |
| 2000 | 2358 | 30 | E | S&D | PAB | 9.8 |
| 2000 | 2358 | 27 | E | S&D | UNK | 265.1 |
| 2000 | 2359 | 76 | E | S&D | KH | 48.2 |
| 2000 | 2361 | 97 | E | S&D | KH | 142 |
| 2000 | 2362 | 7 | E | S&D | PAB | 243.1 |
| 2001 | 2375 | 13 | E | S&D | PAB | 408.5 |
| 2001 | 2378 | 4 | E | 3C | PAB | 1064 |
| 2001 | 2381 | 14 | E | 3C | KH | 262 |
| 2001 | 2381 | 15 | E | 3C | PAB | 458.5 |
| 2001 | 2393 | 1 | E | 3B | PAB | 499 |
| 2001 | 2416 | 1 | E | S&D | UNK | 443.8 |
| 2001 | 2416 | 2 | E | S&D | UNK | 51.9 |
| 2000 | 2501 | 2 | E | S&D | UNK | 309 |
| 2000 | 2502 | 2 | E | S&D | DQ | 560 |
| 2000 | 2502 | 4 | E | S&D | GSS | 241 |
| 2000 | 2502 | 1 | E | S&D | PAB | 265.5 |
| 2000 | 2502 | 3 | E | S&D | PAB | 139.7 |
| 2000 | 2717 | 37 | E | S&D | DQ | 79.6 |
| 2000 | 2719 | 26 | E | S&D | UNK | 37.9 |
| 2000 | 2720 | 21 | E | S&D | UNK | 52.9 |
| 2000 | 2725 | 17 | E | 3C | DQ | 21.6 |
| 2000 | 2726 | 1 | E | 3C | PAB | 497 |
| 2000 | 2726 | 2 | E | 3C | UNK | 240.5 |
| 2000 | 2727 | 19 | E | 3C | UNK | 59.8 |
| 2000 | 2727 | 21 | E | 3C | UNK | 81.5 |
| 2000 | 2728 | 1 | E | 3C | DQ | 445 |
| 2000 | 2728 | 2 | E | 3C | PAB | 150 |
| 2000 | 2753 | 21 | E | 3C | DQ | 62.9 |
| 2000 | 2755 | 23 | E | 3C | PAB | 30.8 |
| 2000 | 2755 | 25 | E | 3C | UNK | 100 |
| 2000 | 2758 | 18 | E | 3C | UNK | 562 |
| 2000 | 2762 | 25 | E | 3C | PAB | 222.4 |
| 2000 | 2763 | 28 | E | 3C | UNK | 92.8 |
| 2000 | 2776 | 39 | E | 3C | DQ | 374 |
| 90 | 3037 | 47 | E | S&D | PAB | 67.4 |
| 90 | 3038 | 8 | E | 3B | UNK | 29.2 |
| 90 | 3040 | 31 | E | S&D | PAB | 1253 |
| 90 | 3040 | 32 | E | S&D | PAB | 834 |
| 90 | 3040 | 33 | E | S&D | PAB | 672 |
| 90 | 3040 | 34 | E | S&D | PAB | 1583 |
| 90 | 3040 | 35 | E | S&D | PAB | 625 |
| 90 | 3040 | 2 | E | S&D | UNK | 271.9 |
| 90 | 3042 | 20 | E | S&D | GSS | 179.5 |
| 2000 | 2227 | 67 | E | S&D | PAB | 7.2 |
| 2000 | 2227 | 374 | E | S&D | PAB | 171.4 |
| 2000 | 2227 | 376 | E | S&D | PAB | 324 |
| 2000 | 2777 | 31 | E | 3C | KH | 77.7 |
| 2000 | 2782 | 7 | E | S&D | PAB | 6 |
| 2000 | 2784 | 5 | E | 3C | PAB | 258.3 |
| 2000 | 2784 | 35 | E | 3C | UNK | 162.9 |
| 2000 | 2789 | 25 | E | 3C | DQ | 310 |
| 2000 | 2794 | 1 | E | 3C | DQ | 804 |
| 2000 | 2795 | 1 | E | 3C | UNK | 268 |
| 2000 | 2824 | 21 | E | 3C | GSS | 1265 |
| 2000 | 2824 | 22 | E | 3C | PAB | 510 |
| 2000 | 2824 | 23 | E | 3C | PAB | 115.6 |
| 2000 | 2824 | 24 | E | 3C | PAB | 209 |
| 2000 | 2825 | 20 | E | 3C | GSS | 721 |
| 2000 | 2836 | 15 | E | 3C | PAB | 279.6 |
| 2000 | 2840 | 12 | E | 3C | UNK | 17.4 |
| 2000 | 2853 | 12 | E | 3C | PAB | 48.3 |
| 2000 | 2853 | 13 | E | 3C | PAB | 35.1 |
| 2000 | 2855 | 8 | E | 3C | UNK | 202.2 |
| 2001 | 2906 | 2 | E | 3B | PAB | 327.2 |
| 2001 | 2911 | 11 | E | 3B | DQ | 92.3 |
| 2001 | 2913 | 157 | E | 3B | PAB | 716.8 |
| 2001 | 2913 | 158 | E | 3B | PAB | 50 |
| 2001 | 2920 | 3 | E | S&D | PAB | 22.9 |
| 2001 | 2920 | 4 | E | S&D | PAB | 941.6 |
| 2001 | 2921 | 6 | E | S&D | PAB | 244.2 |
| 2001 | 2939 | 43 | E | 3B | UNK | 253.1 |
| 2001 | 2940 | 1 | E | 3B | PAB | 3000 |
| 2001 | 2940 | 2 | E | 3B | PAB | 343.8 |
| 2001 | 2944 | 37 | E | 3B | PAB | 79.6 |
| 2001 | 2944 | 38 | E | 3B | PAB | 80.2 |
| 90 | 3000 | 8 | n/a | n/a | DQ | 450 |
| 90 | 3001 | 10 | E | S&D | PAB | 275 |
| 90 | 3007 | 2 | E | S&D | DQ | 60.9 |
| 90 | 3011 | 52 | E | S&D | PAB | 40.7 |
| 90 | 3011 | 53 | E | S&D | PAB | 575.2 |
| 90 | 3011 | 51 | E | S&D | UNK | 500 |
| 90 | 3014 | 15 | E | S&D | PAB | 745.5 |
| 90 | 3022 | 31 | E | S&D | UNK | 180.5 |
| 90 | 3025 | 23 | E | S&D | PAB | 523.3 |
| 90 | 3025 | 24 | E | S&D | PAB | 174.8 |
| 90 | 3025 | 25 | E | S&D | UNK | 131.8 |
| 90 | 3026 | 36 | E | S&D | UNK | 72.8 |
| 90 | 3028 | 82 | E | S&D | DQ | 72.8 |
| 90 | 3028 | 16 | E | S&D | UNK | 1310 |
| 90 | 3028 | 64 | E | S&D | UNK | 164.6 |
| 90 | 3037 | 46 | E | S&D | PAB | 160.4 |
| 90 | 3221 | 21 | E | S&D | DQ | 160.6 |
| 90 | 3221 | 4 | E | S&D | PAB | 398 |
| 90 | 3222 | 27 | E | 3C | PAB | 1358 |
| 90 | 3222 | 57 | E | 3C | PAB | 378.5 |
| 90 | 3222 | 26 | E | 3C | UNK | 137 |
| 90 | 3222 | 55 | E | 3C | UNK | 81.8 |
| 90 | 3223 | 2 | E | 3C | PAB | 124 |
| 90 | 3223 | 12 | E | 3C | UNK | 106 |
| 90 | 3230 | 3 | E | 3C | DQ | 239.1 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 90 | 3042 | 3 | E | S&D | PAB | 438 |
| 90 | 3043 | 1 | E | S&D | PAB | 404.5 |
| 90 | 3063 | 6 | E | 3B | GSS | 60.8 |
| 90 | 3064 | 17 | E | 3B | DQ | 108.8 |
| 90 | 3068 | 3 | E | S&D | GSS | 242.1 |
| 90 | 3068 | 82 | E | S&D | UNK | 191.2 |
| 90 | 3079 | 6 | E | 3B | PAB | 138.3 |
| 90 | 3089 | 13 | E | 3A | PAB | 36.7 |
| 90 | 3091 | 2 | E | 3C | UNK | 51.6 |
| 90 | 3094 | 3 | E | 3C | GSS | 924.5 |
| 90 | 3094 | 2 | E | 3C | PAB | 170.2 |
| 90 | 3094 | 2 | E | 3C | UNK | 150.9 |
| 90 | 3101 | 11 | E | S&D | PAB | 167 |
| 90 | 3101 | 12 | E | S&D | PAB | 94.5 |
| 90 | 3104 | 1 | E | S&D | PAB | 195.7 |
| 90 | 3104 | 27 | E | S&D | UNK | 155.5 |
| 90 | 3106 | 18 | E | 3C | DQ | 85.5 |
| 90 | 3106 | 4 | E | 3C | UNK | 324 |
| 90 | 3107 | 2 | E | 3C | PAB | 168.8 |
| 90 | 3107 | 7 | E | 3C | UNK | 132.8 |
| 90 | 3109 | 15 | E | 3C | UNK | 17.5 |
| 90 | 3111 | 2 | E | 3C | GSS | 477.7 |
| 90 | 3113 | 1 | E | 3C | KH | 104.7 |
| 90 | 3115 | 62 | E | 3C | PAB | 85.2 |
| 90 | 3117 | 1 | E | 3C | PAB | 4200 |
| 90 | 3132 | 8 | E | 3C | UNK | 40 |
| 90 | 3138 | 3 | E | 3B | PAB | 2000 |
| 90 | 3151 | 24 | E | 3B | PAB | 322.3 |
| 90 | 3173 | 12 | E | S&D | SR | 75.7 |
| 90 | 3186 | 14 | E | 3A | KH | 20.6 |
| 90 | 3188 | 29 | E | S&D | PAB | 102.7 |
| 90 | 3188 | 39 | E | S&D | PAB | 988.5 |
| 90 | 3188 | 28 | E | S&D | UNK | 181 |
| 90 | 3191 | 19 | E | S&D | PAB | 122 |
| 90 | 3191 | 20 | E | S&D | UNK | 164.6 |
| 90 | 3221 | 5 | E | S&D | DQ | 244.8 |
| 93 | 3516 | 36 | E | S&D | PAB | 100 |
| 93 | 3517 | 5 | E | S&D | PAB | 66.3 |
| 93 | 3527 | 1 | E | 3C | PAB | 8200 |
| 93 | 3527 | 2 | E | 3C | UNK | 519 |
| 93 | 3527 | 3 | E | 3C | UNK | 359.5 |
| 93 | 3527 | 4 | E | 3C | UNK | 117 |
| 93 | 3530 | 37 | E | S&D | DQ | 75.4 |
| 93 | 3530 | 38 | E | S&D | DQ | 41.5 |
| 93 | 3530 | 48 | E | S&D | DQ | 19.1 |
| 93 | 3530 | 51 | E | S&D | DQ | 1053 |
| 93 | 3530 | 52 | E | S&D | PAB | 55.3 |
| 93 | 3530 | 39 | E | S&D | SR | 24.2 |
| 93 | 3532 | 97 | E | S&D | DQ | 247.5 |
| 93 | 3532 | 98 | E | S&D | DQ | 194.8 |
| 93 | 3532 | 99 | E | S&D | DQ | 103.3 |
| 93 | 3532 | 100 | E | S&D | UNK | 129.8 |
| 93 | 3533 | 94 | E | S&D | DQ | 35.9 |
| 93 | 3533 | 95 | E | S&D | DQ | 8.8 |
| 93 | 3533 | 96 | E | S&D | DQ | 3.1 |
| 93 | 3533 | 90 | E | S&D | PAB | 52.2 |
| 93 | 3533 | 91 | E | S&D | PAB | 25.1 |
| 90 | 3240 | 6 | E | 3C | PAB | 259.5 |
| 90 | 3241 | 3 | E | 3C | PAB | 366.5 |
| 90 | 3247 | 46 | E | S&D | GSS | 343.5 |
| 90 | 3247 | 43 | E | S&D | PAB | 290.2 |
| 90 | 3247 | 44 | E | S&D | PAB | 92.2 |
| 90 | 3247 | 45 | E | S&D | PAB | 127.7 |
| 90 | 3247 | 1 | E | S&D | UNK | 254 |
| 90 | 3253 | 22 | E | 3B | GSS | 918 |
| 90 | 3253 | 17 | E | 3B | PAB | 411 |
| 90 | 3253 | 18 | E | 3B | PAB | 229.4 |
| 90 | 3253 | 19 | E | 3B | PAB | 717.7 |
| 90 | 3253 | 20 | E | 3B | PAB | 34.1 |
| 90 | 3253 | 16 | E | 3B | UNK | 54 |
| 90 | 3265 | 4 | E | S&D | PAB | 68.7 |
| 90 | 3266 | 3 | E | 3B | PAB | 375.5 |
| 90 | 3266 | 4 | E | 3B | UNK | 103.6 |
| 90 | 3277 | 2 | E | 3A | PAB | 109 |
| 90 | 3281 | 16 | E | 3A | UNK | 154.4 |
| 90 | 3289 | 1 | E | 3A | PAB | 892 |
| 90 | 3290 | 25 | E | S&D | PAB | 9.5 |
| 90 | 3290 | 24 | E | S&D | UNK | 171.1 |
| 90 | 3291 | 6 | E | 3C | PAB | 1252 |
| 2000 | 3311 | 1 | E | 3C | UNK | 248.5 |
| 2000 | 3315 | 1 | E | 3C | UNK | 3761 |
| 90 | 3400 | 3 | E | 3B | UNK | 137.5 |
| 90 | 3406 | 15 | E | 3B | PAB | 167.2 |
| 90 | 3430 | 2 | E | 3C | UNK | 183.8 |
| 93 | 3501 | 6 | E | S&D | UNK | 124.8 |
| 93 | 3502 | 42 | E | S&D | PAB | 33.4 |
| 93 | 3504 | 19 | E | 3C | PAB | 50.9 |
| 93 | 3505 | 16 | E | S&D | DQ | 655 |
| 93 | 3506 | 62 | E | S&D | DQ | 96.8 |
| 93 | 3506 | 61 | E | S&D | PAB | 270.9 |
| 93 | 3506 | 67 | E | S&D | PAB | 127 |
| 93 | 3511 | 14 | E | S&D | PAB | 92 |
| 93 | 3515 | 8 | E | 3C | KH | 2 |
| 93 | 3556 | 10 | E | 3C | DQ | 26.2 |
| 93 | 3556 | 8 | E | 3C | UNK | 23.5 |
| 93 | 3557 | 7 | E | S&D | DQ | 73.8 |
| 93 | 3559 | 2 | E | 3C | GSS | 6.5 |
| 93 | 3563 | 15 | E | 3C | PAB | 79.7 |
| 93 | 3564 | 2 | E | 3C | UNK | 39.6 |
| 93 | 3565 | 16 | E | 3C | DQ | 9.5 |
| 93 | 3567 | 3 | E | 3C | DQ | 18.9 |
| 93 | 3574 | 9 | E | 3C | PAB | 19.2 |
| 93 | 3575 | 10 | E | 3C | PAB | 18.4 |
| 93 | 3575 | 24 | E | 3C | PAB | 6.9 |
| 93 | 3596 | 23 | E | 3C | PAB | 2 |
| 93 | 3601 | 27 | E | 3B | KH | 105.6 |
| 93 | 3602 | 19 | E | 3B | PAB | 232.9 |
| 93 | 3604 | 4 | E | 3B | UNK | 24.7 |
| 93 | 3606 | 46 | E | 3B | PAB | 5.6 |
| 93 | 3614 | 6 | E | 2 | PAB | 149.6 |
| 93 | 3623 | 1 | E | 3C | UNK | 73.5 |
| 93 | 3641 | 12 | E | 3B | KH | 76 |
| 93 | 3644 | 7 | E | 3B | UNK | 17.6 |
| 93 | 3645 | 67 | E | 3B | KH | 25.4 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 93 | 3533 | 100 | E | S&D | PAB | 18.7 |
| 93 | 3533 | 101 | E | S&D | PAB | 53.8 |
| 93 | 3534 | 15 | E | S&D | DQ | 11.4 |
| 93 | 3534 | 29 | E | S&D | UNK | 7.4 |
| 93 | 3535 | 30 | E | S&D | PAB | 228 |
| 93 | 3535 | 50 | E | S&D | UNK | 248.3 |
| 93 | 3536 | 6 | E | S&D | UNK | 95.9 |
| 93 | 3536 | 7 | E | S&D | UNK | 53.3 |
| 93 | 3537 | 37 | E | S&D | DQ | 57.4 |
| 93 | 3537 | 38 | E | S&D | DQ | 171 |
| 93 | 3537 | 39 | E | S&D | DQ | 111.2 |
| 93 | 3537 | 35 | E | S&D | PAB | 132.6 |
| 93 | 3537 | 36 | E | S&D | UNK | 90.1 |
| 93 | 3538 | 43 | E | 3C | PAB | 39.4 |
| 93 | 3539 | 8 | E | 3C | DQ | 98.1 |
| 93 | 3541 | 51 | E | 3C | PAB | 608.5 |
| 93 | 3541 | 52 | E | 3C | PAB | 73 |
| 93 | 3544 | 27 | E | 3C | PAB | 75.6 |
| 93 | 3545 | 18 | E | 3C | PAB | 912.5 |
| 93 | 3548 | 11 | E | 3C | PAB | 33.9 |
| 93 | 3552 | 23 | E | S&D | PAB | 67.9 |
| 93 | 3555 | 31 | E | S&D | DQ | 914 |
| 93 | 3555 | 32 | E | S&D | PAB | 103 |
| 93 | 3556 | 9 | E | 3C | DQ | 108.7 |
| 93 | 3803 | 101 | E | S&D | UNK | 46.5 |
| 93 | 3804 | 57 | E | S&D | PAB | 1076 |
| 93 | 3804 | 58 | E | S&D | PAB | 124.5 |
| 93 | 3804 | 23 | E | S&D | UNK | 46.3 |
| 93 | 3804 | 54 | E | S&D | UNK | 63.7 |
| 93 | 3804 | 55 | E | S&D | UNK | 29.8 |
| 93 | 3806 | 71 | E | 3C | UNK | 96.8 |
| 93 | 3809 | 13 | E | 3C | DQ | 98.9 |
| 93 | 3811 | 4 | E | 3C | DQ | 144.7 |
| 93 | 3812 | 10 | E | 3C | UNK | 74.6 |
| 93 | 3813 | 3 | E | 3C | UNK | 43.2 |
| 93 | 3814 | 8 | E | 3C | UNK | 126.8 |
| 93 | 3829 | 3 | E | S&D | GSS | 1486 |
| 93 | 3830 | 1 | E | S&D | DQ | 84.7 |
| 93 | 3830 | 2 | E | S&D | DQ | 40.1 |
| 93 | 3831 | 7 | E | S&D | DQ | 718.3 |
| 93 | 3831 | 8 | E | S&D | DQ | 858.3 |
| 93 | 3832 | 8 | E | S&D | PAB | 39.7 |
| 93 | 3833 | 11 | E | S&D | UNK | 118.9 |
| 93 | 3834 | 6 | E | S&D | DQ | 35.9 |
| 93 | 3834 | 7 | E | S&D | PAB | 170 |
| 93 | 3834 | 8 | E | S&D | UNK | 77.6 |
| 93 | 3835 | 8 | E | S&D | DQ | 69.4 |
| 93 | 3835 | 10 | E | S&D | PAB | 263.4 |
| 93 | 3836 | 25 | E | S&D | DQ | 52.1 |
| 93 | 3836 | 29 | E | S&D | DQ | 205.3 |
| 93 | 3836 | 4 | E | S&D | PAB | 21.2 |
| 93 | 3836 | 26 | E | S&D | PAB | 56.9 |
| 93 | 3836 | 30 | E | S&D | PAB | 161.8 |
| 93 | 3836 | 31 | E | S&D | PAB | 176.6 |
| 93 | 3836 | 24 | E | S&D | UNK | 52 |
| 93 | 3838 | 12 | E | S&D | PAB | 416.7 |
| 93 | 3839 | 33 | E | S&D | DQ | 510 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 93 | 3649 | 9 | E | 3A | KH | 156.6 |
| 93 | 3700 | 40 | E | S&D | DQ | 236.5 |
| 93 | 3700 | 41 | E | S&D | UNK | 36.4 |
| 93 | 3704 | 11 | E | 3C | DQ | 189 |
| 93 | 3705 | 5 | E | S&D | DQ | 52.6 |
| 93 | 3705 | 4 | E | S&D | UNK | 365 |
| 93 | 3707 | 13 | E | 3C | PAB | 33.6 |
| 93 | 3709 | 21 | E | S&D | DQ | 65.5 |
| 93 | 3709 | 22 | E | S&D | DQ | 72.2 |
| 93 | 3709 | 15 | E | S&D | PAB | 95.8 |
| 93 | 3710 | 14 | E | 3C | DQ | 84.5 |
| 93 | 3710 | 28 | E | 3C | DQ | 45.8 |
| 93 | 3710 | 27 | E | 3C | PAB | 63 |
| 93 | 3710 | 30 | E | 3C | PAB | 29.3 |
| 93 | 3710 | 29 | E | 3C | UNK | 7.7 |
| 93 | 3714 | 4 | E | 3C | PAB | 439 |
| 93 | 3716 | 11 | E | 3C | PAB | 19.5 |
| 93 | 3739 | 36 | E | S&D | DQ | 65.4 |
| 93 | 3802 | 7 | E | S&D | DQ | 88 |
| 93 | 3802 | 9 | E | S&D | DQ | 52.4 |
| 93 | 3802 | 6 | E | S&D | PAB | 222.4 |
| 93 | 3802 | 8 | E | S&D | UNK | 131.5 |
| 93 | 3803 | 37 | E | S&D | DQ | 214.1 |
| 93 | 3803 | 35 | E | S&D | PAB | 245.5 |
| 93 | 3864 | 9 | E | 3C | DQ | 116.7 |
| 93 | 3864 | 10 | E | 3C | DQ | 132.4 |
| 93 | 3864 | 21 | E | 3C | PAB | 191.7 |
| 93 | 3864 | 23 | E | 3C | PAB | 122.6 |
| 93 | 3865 | 37 | E | 3C | GSS | 107 |
| 93 | 3865 | 29 | E | 3C | PAB | 104.7 |
| 93 | 3865 | 44 | E | 3C | PAB | 106.8 |
| 93 | 3865 | 4 | E | 3C | UNK | 165.9 |
| 93 | 3866 | 8 | E | 3C | PAB | 31.1 |
| 93 | 3866 | 32 | E | 3C | UNK | 123.6 |
| 93 | 3866 | 40 | E | 3C | UNK | 10.5 |
| 93 | 3866 | 41 | E | 3C | UNK | 91.9 |
| 93 | 3867 | 48 | E | 3C | UNK | 19.3 |
| 93 | 3868 | 11 | E | 3C | DQ | 63.7 |
| 93 | 3868 | 12 | E | 3C | DQ | 66.2 |
| 93 | 3869 | 47 | E | 3C | DQ | 30.4 |
| 93 | 3869 | 52 | E | 3C | DQ | 34.2 |
| 93 | 3869 | 5 | E | 3C | UNK | 447.4 |
| 93 | 3873 | 12 | E | S&D | DQ | 8.5 |
| 93 | 3876 | 6 | E | S&D | PAB | 252.6 |
| 94 | 3879 | 8 | E | S&D | DQ | 91.3 |
| 94 | 3879 | 9 | E | S&D | DQ | 4.5 |
| 94 | 3879 | 23 | E | S&D | DQ | 19.6 |
| 94 | 3879 | 21 | E | S&D | KH | 59.4 |
| 94 | 3879 | 22 | E | S&D | PAB | 22.7 |
| 93 | 3887 | 10 | E | 3C | GSS | 130.7 |
| 93 | 3888 | 22 | E | 3C | UNK | 23.7 |
| 93 | 3890 | 15 | E | 3C | DQ | 112.6 |
| 93 | 3891 | 20 | E | 3C | DQ | 119.8 |
| 93 | 3891 | 24 | E | 3C | DQ | 95 |
| 93 | 3891 | 25 | E | 3C | GSS | 221.1 |
| 93 | 3892 | 14 | E | 3C | DQ | 25.5 |
| 93 | 3892 | 57 | E | 3C | DQ | 583.5 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 93 | 3839 | 35 | E | S&D | DQ | 17.6 |
| 93 | 3839 | 69 | E | S&D | DQ | 211.8 |
| 93 | 3839 | 37 | E | S&D | PAB | 62.3 |
| 93 | 3839 | 38 | E | S&D | PAB | 117.9 |
| 93 | 3839 | 36 | E | S&D | UNK | 53.2 |
| 93 | 3840 | 1 | E | 3C | DQ | 76.1 |
| 93 | 3841 | 17 | E | S&D | DQ | 76.5 |
| 93 | 3860 | 2 | E | S&D | DQ | 22 |
| 93 | 3861 | 2 | E | S&D | DQ | 37.6 |
| 93 | 3862 | 7 | E | S&D | PAB | 40.3 |
| 93 | 3863 | 20 | E | S&D | DQ | 44.4 |
| 93 | 3863 | 19 | E | S&D | UNK | 56.8 |
| 93 | 3892 | 73 | E | 3C | UNK | 55.2 |
| 94 | 3899 | 3 | E | S&D | UNK | 143.3 |
| 94 | 3899 | 4 | E | S&D | UNK | 130.5 |
| 94 | 3903 | 29 | E | S&D | PAB | 21.2 |
| 94 | 3903 | 34 | E | S&D | PAB | 117.2 |
| 94 | 3904 | 25 | E | 3C | PAB | 204.6 |
| 94 | 3904 | 26 | E | 3C | PAB | 109.6 |
| 94 | 3904 | 29 | E | 3C | UNK | 74.5 |
| 94 | 3904 | 43 | E | 3C | UNK | 117.4 |
| 94 | 3912 | 7 | E | 3C | UNK | 40 |
| 94 | 3917 | 15 | E | 3C | PAB | 66.9 |
| 94 | 3918 | 2 | E | 3C | DQ | 99.1 |
| 94 | 3921 | 4 | E | 3C | PAB | 121.5 |
| 94 | 3922 | 4 | E | 3C | UNK | 120.4 |
| 94 | 3924 | 19 | E | 3C | DQ | 912.5 |
| 94 | 3931 | 6 | E | 3C | PAB | 94.9 |
| 94 | 3931 | 8 | E | 3C | PAB | 11.3 |
| 94 | 3935 | 25 | E | 3C | DQ | 115.2 |
| 94 | 3935 | 26 | E | 3C | DQ | 62.7 |
| 94 | 3935 | 27 | E | 3C | DQ | 46.4 |
| 94 | 3935 | 29 | E | 3C | DQ | 19.7 |
| 94 | 3935 | 28 | E | 3C | PAB | 27.8 |
| 94 | 3935 | 30 | E | 3C | PAB | 15.9 |
| 94 | 3940 | 2 | E | S&D | DQ | 47 |
| 94 | 3942 | 1 | E | 3C | DQ | 602.3 |
| 94 | 3942 | 2 | E | 3C | DQ | 936.1 |
| 94 | 3946 | 61 | E | 3C | DQ | 108 |
| 94 | 3946 | 62 | E | 3C | PAB | 92 |
| 94 | 3947 | 19 | E | 3C | UNK | 600 |
| 94 | 3951 | 29 | Tr.21 | S&D | PAB | 185.9 |
| 94 | 3965 | 32 | Tr.21 | 3B | PAB | 108 |
| 94 | 3966 | 6 | Tr.21 | 3B | PAB | 632.3 |
| 94 | 3984 | 59 | E | S&D | UNK | 136.5 |
| 94 | 3985 | 41 | E | 3C | DQ | 52.5 |
| 94 | 3985 | 42 | E | 3C | DQ | 18 |
| 94 | 3987 | 36 | E | 3C | PAB | 149 |
| 94 | 3989 | 11 | E | 3C | PAB | 75.9 |
| 94 | 3998 | 11 | E | 3C | PAB | 145.8 |
| 93 | 4004 | 8 | ET | S&D | UNK | 28.9 |
| 93 | 4016 | 10 | ET | S&D | PAB | 750 |
| 93 | 4016 | 9 | ET | S&D | UNK | 283.5 |
| 93 | 4030 | 6 | ET | S&D | PAB | 206.1 |
| 93 | 4041 | 1 | ET | S&D | UNK | 57.6 |
| 93 | 4046 | 1 | ET | 3B | PAB | 559.9 |
| 93 | 4051 | 2 | ET | S&D | PAB | 419.9 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 93 | 3892 | 59 | E | 3C | DQ | 18.5 |
| 93 | 3892 | 60 | E | 3C | DQ | 13.4 |
| 93 | 3892 | 61 | E | 3C | DQ | 60.6 |
| 93 | 3892 | 62 | E | 3C | DQ | 34.7 |
| 93 | 3892 | 63 | E | 3C | DQ | 77.9 |
| 93 | 3892 | 64 | E | 3C | DQ | 47.5 |
| 93 | 3892 | 74 | E | 3C | DQ | 67.4 |
| 93 | 3892 | 13 | E | 3C | PAB | 392.4 |
| 93 | 3892 | 66 | E | 3C | PAB | 14.6 |
| 93 | 3892 | 67 | E | 3C | PAB | 82.5 |
| 93 | 3892 | 75 | E | 3C | PAB | 237.6 |
| 93 | 3892 | 65 | E | 3C | UNK | 53.9 |
| 93 | 4051 | 12 | ET | S&D | PAB | 223 |
| 93 | 4065 | 73 | ET | 3B | KH | 11.7 |
| 93 | 4065 | 71 | ET | 3B | PAB | 928.5 |
| 93 | 4065 | 72 | ET | 3B | PAB | 46.4 |
| 93 | 4069 | 9 | ET | 3B | PAB | 296.3 |
| 93 | 4069 | 10 | ET | 3B | PAB | 310.2 |
| 93 | 4074 | 33 | ET | 3C | PAB | 399 |
| 93 | 4090 | 14 | ET | 3B | PAB | 28.1 |
| 93 | 4098 | 16 | ET | 3B | PAB | 2800 |
| 93 | 4099 | 2 | ET | 3B | KH | 64.4 |
| 93 | 4100 | 3 | ET | 3C | UNK | 164 |
| 93 | 4100 | 13 | ET | 3C | UNK | 29.3 |
| 93 | 4106 | 41 | ET | 3C | GSS | 43.1 |
| 93 | 4111 | 10 | ET | 3C | UNK | 120 |
| 93 | 4128 | 7 | ET | 3B | PAB | 149.6 |
| 93 | 4161 | 22 | ET | 3B | KH | 64.8 |
| 93 | 4193 | 38 | ET | 3C | GSS | 18.1 |
| 93 | 4200 | 23 | ET | S&D | UNK | 216.3 |
| 93 | 4213 | 1 | ET | S&D | PAB | 1219 |
| 93 | 4250 | 24 | ET | 3B | PAB | 972.5 |
| 93 | 4255 | 5 | ET | S&D | PAB | 138 |
| 93 | 4302 | 19 | E | 3B | PAB | 22 |
| 93 | 4314 | 2 | ET | S&D | PAB | 161.3 |
| 93 | 4325 | 1 | E | 2 | PAB | 470 |
| 93 | 4330 | 4 | E | 3B | PAB | 309 |
| 93 | 4330 | 14 | E | 3B | PAB | 199 |
| 93 | 4335 | 10 | E | 2 | PAB | 1178 |
| 93 | 4341 | 5 | E | 2 | UNK | 6.1 |
| 95 | 4411 | 18 | ET | S&D | UNK | 164.2 |
| 95 | 4415 | 15 | ET | S&D | PAB | 260.6 |
| 95 | 4415 | 16 | ET | S&D | PAB | 94.3 |
| 95 | 4416 | 34 | ET | 3C | PAB | 536.5 |
| 95 | 4423 | 78 | ET | S&D | GSS | 274.2 |
| 95 | 4423 | 32 | ET | S&D | PAB | 33.1 |
| 95 | 4427 | 14 | ET | S&D | UNK | 256.7 |
| 95 | 4433 | 31 | ET | S&D | UNK | 175.1 |
| 95 | 4442 | 5 | ET | 3C | PAB | 150.4 |
| 95 | 4445 | 381 | ET | S&D | PAB | 182.2 |
| 95 | 4461 | 3 | ET | 3C | PAB | 423.9 |
| 95 | 4463 | 2 | ET | 3C | PAB | 421.1 |
| 95 | 4463 | 3 | ET | 3C | PAB | 773.9 |
| 95 | 4463 | 4 | ET | 3C | PAB | 527.6 |
| 95 | 4463 | 5 | ET | 3C | PAB | 1722 |
| 95 | 4466 | 45 | ET | S&D | PAB | 626.6 |
| 95 | 4466 | 65 | ET | S&D | PAB | 23 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 95 | 4466 | 66 | ET | S&D | PAB | 7.1 |
| 95 | 4468 | 1 | E | 3B | PAB | 436 |
| 95 | 4484 | 1 | E | 3A | PAB | 374 |
| 95 | 4545 | 9 | ET | 3B | UNK | 68 |
| 95 | 4565 | 2 | ET | 3B | PAB | 2980 |
| 95 | 4572 | 1 | ET | 3B | UNK | 717.4 |
| 95 | 4587 | 1 | ET | 3B | PAB | 224.2 |
| 95 | 4606 | 35 | ET | 3B | PAB | 312.3 |
| 95 | 4607 | 47 | ET | S&D | DQ | 242 |
| 95 | 4607 | 7 | ET | S&D | KH | 306 |
| 95 | 4609 | 208 | ET | S&D | DQ | 261.7 |
| 95 | 4609 | 40 | ET | S&D | PAB | 794.3 |
| 95 | 4609 | 41 | ET | S&D | PAB | 90 |
| 95 | 4609 | 44 | ET | S&D | PAB | 659.5 |
| 95 | 4609 | 45 | ET | S&D | PAB | 594.2 |
| 95 | 4609 | 124 | ET | S&D | PAB | 173 |
| 95 | 4609 | 181 | ET | S&D | PAB | 112.5 |
| 95 | 4611 | 14 | ET | 3B | PAB | 16 |
| 95 | 4613 | 3 | ET | 3B | PAB | 336.5 |
| 95 | 4613 | 43 | ET | 3B | PAB | 185.2 |
| 95 | 4614 | 44 | ET | 3B | DQ | 201.3 |
| 95 | 4614 | 1 | ET | 3B | PAB | 190.8 |
| 95 | 4614 | 42 | ET | 3B | PAB | 158.2 |
| 95 | 4614 | 43 | ET | 3B | PAB | 154.7 |
| 95 | 4614 | 46 | ET | 3B | PAB | 138.8 |
| 95 | 4614 | 40 | ET | 3B | UNK | 180 |
| 95 | 4615 | 2 | ET | 3C | PAB | 153.5 |
| 95 | 4623 | 38 | ET | S&D | DQ | 291.1 |
| 95 | 4623 | 114 | ET | S&D | DQ | 58.5 |
| 95 | 4623 | 23 | ET | S&D | PAB | 345.9 |
| 95 | 4623 | 113 | ET | S&D | PAB | 375.5 |
| 95 | 4623 | 115 | ET | S&D | PAB | 30 |
| 95 | 4623 | 119 | ET | S&D | PAB | 418.3 |
| 95 | 4624 | 5 | ET | 3C | PAB | 63.7 |
| 95 | 4647 | 66 | ET | S&D | DQ | 77 |
| 95 | 4647 | 19 | ET | S&D | PAB | 170.8 |
| 95 | 4651 | 3 | ET | S&D | PAB | 80.5 |
| 95 | 4654 | 18 | ET | 3B | PAB | 21.9 |
| 95 | 4665 | 1 | ET | 3B | PAB | 992.8 |
| 95 | 4667 | 1 | ET | S&D | PAB | 1419 |
| 95 | 4667 | 14 | ET | S&D | PAB | 213.7 |
| 95 | 4669 | 4 | ET | 3B | DQ | 1160 |
| 95 | 4669 | 6 | ET | 3B | PAB | 288.3 |
| 95 | 4681 | 11 | ET | 3B | PAB | 362.9 |
| 95 | 4687 | 2 | ET | 3B | GSS | 300.2 |
| 95 | 4725 | 6 | ET | 3C | PAB | 778.4 |
| 95 | 4726 | 110 | ET | 3C | DQ | 562.3 |
| 95 | 4726 | 112 | ET | 3C | DQ | 6 |
| 95 | 4726 | 212 | ET | 3C | DQ | 176 |
| 95 | 4726 | 215 | ET | 3C | GSS | 10.5 |
| 95 | 4726 | 113 | ET | 3C | PAB | 394 |
| 95 | 4726 | 213 | ET | 3C | UNK | 344.6 |
| 95 | 4726 | 214 | ET | 3C | UNK | 3.98 |
| 95 | 4728 | 214 | ET | 3C | GSS | 255.5 |
| 95 | 4731 | 6 | ET | 3C | DQ | 13.5 |
| 95 | 4733 | 52 | ET | 3C | DQ | 52 |
| 95 | 4733 | 23 | ET | 3C | GSS | 161.5 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 95 | 4687 | 1 | ET | 3B | UNK | 438.7 |
| 94 | 4700 | 4 | ET | S&D | DQ | 27.9 |
| 94 | 4700 | 6 | ET | S&D | DQ | 131.5 |
| 94 | 4700 | 7 | ET | S&D | DQ | 70.6 |
| 94 | 4700 | 8 | ET | S&D | DQ | 15.4 |
| 94 | 4700 | 10 | ET | S&D | DQ | 34.8 |
| 94 | 4700 | 5 | ET | S&D | PAB | 133.9 |
| 94 | 4700 | 9 | ET | S&D | UNK | 15.1 |
| 94 | 4701 | 6 | ET | S&D | DQ | 40.9 |
| 94 | 4701 | 7 | ET | S&D | DQ | 37.8 |
| 94 | 4702 | 31 | ET | S&D | DQ | 29.8 |
| 94 | 4702 | 32 | ET | S&D | DQ | 43.8 |
| 94 | 4702 | 33 | ET | S&D | DQ | 19.6 |
| 94 | 4702 | 34 | ET | S&D | DQ | 31.4 |
| 94 | 4702 | 12 | ET | S&D | PAB | 30.5 |
| 94 | 4702 | 30 | ET | S&D | PAB | 143.5 |
| 94 | 4702 | 11 | ET | S&D | UNK | 92.9 |
| 94 | 4704 | 47 | ET | 3C | DQ | 22.6 |
| 94 | 4704 | 30 | ET | 3C | GSS | 61.5 |
| 94 | 4707 | 10 | ET | S&D | DQ | 394.4 |
| 94 | 4707 | 17 | ET | S&D | PAB | 7 |
| 94 | 4707 | 33 | ET | S&D | UNK | 21.7 |
| 94 | 4712 | 8 | ET | 3C | UNK | 200.5 |
| 94 | 4714 | 10 | ET | 3C | PAB | 44.4 |
| 95 | 4716 | 4 | ET | S&D | DQ | 1577 |
| 95 | 4716 | 3 | ET | S&D | PAB | 71.4 |
| 95 | 4719 | 84 | ET | 3C | DQ | 13 |
| 95 | 4719 | 85 | ET | 3C | DQ | 10 |
| 95 | 4719 | 171 | ET | 3C | PAB | 106 |
| 95 | 4719 | 172 | ET | 3C | PAB | 148.7 |
| 95 | 4719 | 82 | ET | 3C | UNK | 31.99 |
| 95 | 4719 | 83 | ET | 3C | UNK | 10.5 |
| 95 | 4719 | 113 | ET | 3C | UNK | 127 |
| 95 | 4719 | 114 | ET | 3C | UNK | 101.6 |
| 95 | 4720 | 112 | ET | 3C | DQ | 740.5 |
| 95 | 4721 | 4 | ET | 3C | DQ | 224.9 |
| 95 | 4721 | 5 | ET | 3C | DQ | 177.6 |
| 95 | 4721 | 132 | ET | 3C | DQ | 57.2 |
| 95 | 4721 | 3 | ET | 3C | UNK | 188.2 |
| 95 | 4721 | 6 | ET | 3C | UNK | 208 |
| 95 | 4721 | 133 | ET | 3C | UNK | 54.5 |
| 95 | 4723 | 108 | ET | 3C | PAB | 285.6 |
| 95 | 4723 | 111 | ET | 3C | PAB | 134 |
| 95 | 4724 | 15 | ET | 3C | PAB | 31.3 |
| 95 | 4724 | 86 | ET | 3C | PAB | 1012 |
| 95 | 4916 | 139 | ET | 3C | UNK | 48.2 |
| 95 | 4917 | 9 | ET | 3C | DQ | 83.4 |
| 95 | 4917 | 20 | ET | 3C | GSS | 66.8 |
| 95 | 4917 | 10 | ET | 3C | UNK | 136.1 |
| 95 | 4918 | 5 | ET | 3C | PAB | 244.9 |
| 95 | 4918 | 12 | ET | 3C | PAB | 54.2 |
| 95 | 4919 | 13 | ET | 3C | DQ | 42.4 |
| 95 | 4919 | 14 | ET | 3C | DQ | 671.6 |
| 95 | 4919 | 15 | ET | 3C | PAB | 143.1 |
| 95 | 4919 | 16 | ET | 3C | PAB | 266 |
| 95 | 4919 | 26 | ET | 3C | PAB | 79 |
| 95 | 4920 | 3 | ET | 3C | PAB | 19.3 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 95 | 4733 | 22 | ET | 3C | UNK | 110 |
| 95 | 4734 | 4 | ET | 3C | GSS | 315 |
| 95 | 4734 | 40 | ET | 3C | PAB | 185 |
| 95 | 4737 | 2 | ET | 3C | PAB | 467.5 |
| 95 | 4738 | 7 | ET | 3C | PAB | 370 |
| 95 | 4738 | 5 | ET | 3C | UNK | 23.5 |
| 95 | 4740 | 2 | ET | 3C | PAB | 664.5 |
| 95 | 4741 | 1 | ET | 3C | DQ | 235 |
| 95 | 4743 | 1 | ET | 3C | DQ | 278 |
| 95 | 4751 | 5 | ET | 3C | DQ | 88.5 |
| 95 | 4751 | 19 | ET | 3C | PAB | 44.5 |
| 95 | 4752 | 8 | ET | 3C | DQ | 602.5 |
| 94 | 4803 | 1 | ET | S&D | DQ | 478.6 |
| 94 | 4803 | 2 | ET | S&D | DQ | 647.3 |
| 94 | 4805 | 3 | ET | S&D | DQ | 257.1 |
| 94 | 4810 | 251 | ET | 3C | PAB | 13.5 |
| 94 | 4819 | 9 | ET | S&D | DQ | 540.2 |
| 94 | 4819 | 7 | ET | S&D | UNK | 492.4 |
| 94 | 4824 | 6 | ET | 3C | KH | 421 |
| 94 | 4857 | 6 | ET | S&D | PAB | 102.7 |
| 94 | 4860 | 25 | ET | S&D | UNK | 354 |
| 94 | 4860 | 27 | ET | S&D | UNK | 86.8 |
| 95 | 4910 | 40 | ET | 3C | DQ | 11.9 |
| 95 | 4910 | 41 | ET | 3C | DQ | 23.9 |
| 95 | 4910 | 42 | ET | 3C | DQ | 19 |
| 95 | 4910 | 39 | ET | 3C | UNK | 3.8 |
| 95 | 4911 | 16 | ET | 3C | PAB | 198 |
| 95 | 4911 | 113 | ET | 3C | PAB | 592 |
| 95 | 4913 | 10 | ET | 3C | UNK | 102 |
| 95 | 4913 | 11 | ET | 3C | UNK | 18.3 |
| 95 | 4916 | 51 | ET | 3C | DQ | 55.2 |
| 95 | 4916 | 52 | ET | 3C | PAB | 175.8 |
| 95 | 4916 | 50 | ET | 3C | UNK | 18.7 |
| 95 | 4960 | 23 | ET | S&D | UNK | 12.8 |
| 95 | 4961 | 4 | ET | 3C | GSS | 280.7 |
| 95 | 4961 | 2 | ET | 3C | PAB | 189 |
| 95 | 4961 | 3 | ET | 3C | PAB | 335 |
| 95 | 4961 | 5 | ET | 3C | PAB | 1111 |
| 95 | 4962 | 124 | ET | S&D | GSS | 11.3 |
| 95 | 4963 | 6 | ET | 3C | DQ | 492 |
| 95 | 4963 | 38 | ET | 3C | DQ | 304.7 |
| 95 | 4970 | 54 | ET | 3C | DQ | 134.2 |
| 95 | 4973 | 4 | ET | 3C | DQ | 29.3 |
| 95 | 4973 | 15 | ET | 3C | DQ | 338.5 |
| 95 | 4973 | 3 | ET | 3C | UNK | 58.2 |
| 95 | 4974 | 86 | ET | 3C | UNK | 1435 |
| 95 | 4976 | 1 | ET | 3C | PAB | 62.9 |
| 95 | 4978 | 42 | ET | 3C | PAB | 533.4 |
| 95 | 4980 | 6 | ET | S&D | PAB | 300 |
| 95 | 4980 | 7 | ET | S&D | UNK | 130.5 |
| 95 | 4980 | 8 | ET | S&D | UNK | 1125 |
| 95 | 4981 | 59 | ET | S&D | GSS | 128.4 |
| 95 | 4981 | 38 | ET | S&D | PAB | 468.3 |
| 95 | 4981 | 39 | ET | S&D | PAB | 117.5 |
| 95 | 4981 | 40 | ET | S&D | PAB | 234.7 |
| 95 | 4981 | 60 | ET | S&D | PAB | 388.7 |
| 95 | 4981 | 66 | ET | S&D | UNK | 77.5 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 95 | 4921 | 25 | ET | 3C | DQ | 8.9 |
| 95 | 4921 | 26 | ET | 3C | DQ | 31.6 |
| 95 | 4921 | 31 | ET | 3C | PAB | 38.9 |
| 95 | 4921 | 139 | ET | 3C | PAB | 108.7 |
| 95 | 4922 | 4 | ET | 3C | PAB | 318.5 |
| 95 | 4922 | 18 | ET | 3C | PAB | 57 |
| 95 | 4922 | 75 | ET | 3C | PAB | 2500 |
| 95 | 4923 | 101 | ET | 3C | UNK | 17 |
| 95 | 4926 | 215 | ET | 3C | PAB | 539 |
| 95 | 4933 | 16 | ET | S&D | PAB | 88 |
| 95 | 4934 | 107 | ET | S&D | UNK | 91 |
| 95 | 4935 | 20 | ET | S&D | DQ | 27 |
| 95 | 4935 | 44 | ET | S&D | UNK | 46.3 |
| 95 | 4936 | 19 | ET | 3C | UNK | 75.9 |
| 95 | 4940 | 107 | ET | 3C | DQ | 42.6 |
| 95 | 4940 | 75 | ET | 3C | PAB | 184.9 |
| 95 | 4940 | 109 | ET | 3C | UNK | 309.9 |
| 95 | 4941 | 6 | ET | 3C | DQ | 246.6 |
| 95 | 4942 | 4 | ET | S&D | PAB | 190.3 |
| 95 | 4942 | 3 | ET | S&D | UNK | 916.1 |
| 95 | 4943 | 34 | ET | S&D | DQ | 347.1 |
| 95 | 4943 | 51 | ET | S&D | DQ | 33.5 |
| 95 | 4943 | 12 | ET | S&D | GSS | 60.5 |
| 95 | 4943 | 57 | ET | S&D | PAB | 57.4 |
| 95 | 4945 | 35 | ET | 3C | PAB | 533.6 |
| 95 | 4949 | 1 | ET | S&D | UNK | 8.3 |
| 95 | 4949 | 2 | ET | S&D | UNK | 87.2 |
| 95 | 4950 | 1 | ET | 3C | PAB | 142.7 |
| 95 | 4952 | 45 | ET | 3C | DQ | 104.3 |
| 95 | 4953 | 171 | ET | 3C | KH | 126.7 |
| 95 | 4953 | 208 | ET | 3C | UNK | 2.5 |
| 95 | 4954 | 2 | ET | 3C | PAB | 77.3 |
| 95 | 4960 | 28 | ET | S&D | DQ | 149.8 |
| 94 | 5044 | 11 | MS | S&D | DQ | 28.3 |
| 94 | 5044 | 9 | MS | S&D | PAB | 73.4 |
| 94 | 5044 | 10 | MS | S&D | UNK | 138.8 |
| 94 | 5046 | 50 | MS | 3C | DQ | 29 |
| 94 | 5051 | 1 | MS | S&D | UNK | 500 |
| 94 | 5063 | 78 | MS | 3C | UNK | 17.1 |
| 94 | 5070 | 1 | MS | 3C | DQ | 30.2 |
| 94 | 5076 | 41 | MS | 3C | DQ | 16.5 |
| 94 | 5076 | 40 | MS | 3C | UNK | 161.1 |
| 94 | 5076 | 42 | MS | 3C | UNK | 179.7 |
| 94 | 5084 | 3 | MS | 3C | PAB | 234 |
| 94 | 5101 | 1 | E | 3C | PAB | 324 |
| 94 | 5101 | 29 | E | 3C | UNK | 527.5 |
| 95 | 5142 | 21 | E | S&D | PAB | 679.8 |
| 95 | 5144 | 12 | E | 3C | DQ | 105.6 |
| 95 | 5144 | 166 | E | 3C | DQ | 745.2 |
| 95 | 5144 | 11 | E | 3C | UNK | 219.2 |
| 95 | 5145 | 20 | E | 3C | DQ | 431.1 |
| 95 | 5145 | 96 | E | 3C | DQ | 177.5 |
| 95 | 5145 | 71 | E | 3C | KH | 311.7 |
| 95 | 5145 | 62 | E | 3C | PAB | 567.4 |
| 95 | 5145 | 63 | E | 3C | UNK | 63.4 |
| 95 | 5145 | 97 | E | 3C | UNK | 62.9 |
| 95 | 5146 | 62 | E | 3C | DQ | 54.2 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 95 | 4982 | 102 | ET | S&D | DQ | 76.6 |
| 95 | 4982 | 2 | ET | S&D | PAB | 507.3 |
| 95 | 4982 | 122 | ET | S&D | PAB | 60.6 |
| 95 | 4982 | 123 | ET | S&D | UNK | 22.5 |
| 95 | 4986 | 40 | ET | S&D | KH | 201.7 |
| 95 | 4986 | 37 | ET | S&D | PAB | 447 |
| 95 | 4986 | 1 | ET | S&D | UNK | 21.9 |
| 95 | 4988 | 44 | ET | 3C | PAB | 4988 |
| 95 | 4989 | 91 | ET | 3C | DQ | 45.1 |
| 95 | 4989 | 4 | ET | 3C | GSS | 397.9 |
| 95 | 4989 | 47 | ET | 3C | PAB | 321 |
| 95 | 4989 | 48 | ET | 3C | PAB | 252.9 |
| 95 | 4991 | 2 | ET | 3C | DQ | 106 |
| 95 | 4991 | 1 | ET | 3C | PAB | 104.8 |
| 95 | 4992 | 3 | ET | 3C | GSS | 644.2 |
| 93 | 5024 | 23 | MS | 3C | UNK | 335.8 |
| 93 | 5030 | 32 | MS | 3C | GSS | 307.7 |
| 94 | 5039 | 13 | MS | 3C | PAB | 159.7 |
| 94 | 5039 | 15 | MS | 3C | UNK | 225 |
| 94 | 5040 | 17 | MS | S&D | PAB | 99.8 |
| 94 | 5042 | 33 | MS | 3C | DQ | 138.3 |
| 94 | 5200 | 17 | MS | S&D | PAB | 111.5 |
| 94 | 5200 | 18 | MS | S&D | PAB | 86.5 |
| 94 | 5200 | 19 | MS | S&D | PAB | 20.8 |
| 94 | 5202 | 5 | MS | S&D | DQ | 163.6 |
| 94 | 5204 | 4 | MS | S&D | UNK | 34.3 |
| 94 | 5207 | 1 | MS | S&D | DQ | 168 |
| 94 | 5251 | 31 | ET | S&D | DQ | 60.5 |
| 94 | 5251 | 32 | ET | S&D | PAB | 29 |
| 94 | 5344 | 1 | ET | 3B | UNK | 5500 |
| 94 | 5406 | 6 | ET | S&D | PAB | 732.9 |
| 94 | 5501 | 28 | ET | 3B | DQ | 446.6 |
| 94 | 5502 | 61 | ET | 3B | GSS | 279.7 |
| 94 | 5505 | 1 | ET | 3B | PAB | 288.1 |
| 95 | 5517 | 8 | ET | 3B | PAB | 62.7 |
| 95 | 5526 | 10 | ET | 3B | GSS | 802 |
| 95 | 5602 | 13 | ET | S&D | DQ | 234.6 |
| 95 | 5602 | 12 | ET | S&D | PAB | 331.1 |
| 95 | 5603 | 34 | ET | S&D | DQ | 34.8 |
| 95 | 5604 | 15 | ET | S&D | UNK | 34.2 |
| 95 | 5606 | 22 | ET | S&D | PAB | 20.6 |
| 95 | 5607 | 18 | ET | S&D | PAB | 210.7 |
| 95 | 5614 | 21 | ET | S&D | PAB | 58.7 |
| 95 | 5614 | 22 | ET | S&D | PAB | 1052 |
| 95 | 5616 | 1 | ET | 3B | PAB | 244.3 |
| 95 | 5625 | 4 | ET | 3B | PAB | 126.2 |
| 95 | 5625 | 21 | ET | 3B | PAB | 448.3 |
| 95 | 5625 | 22 | ET | 3B | PAB | 405.2 |
| 95 | 5629 | 8 | ET | S&D | PAB | 318 |
| 95 | 5631 | 18 | ET | 3B | PAB | 431.1 |
| 95 | 5669 | 8 | ET | 3B | DQ | 108.7 |
| 95 | 5684 | 31 | ET | 3B | UNK | 181 |
| 95 | 5685 | 13 | ET | 3B | PAB | 816.7 |
| 95 | 5702 | 17 | ET | S&D | DQ | 5.4 |
| 95 | 5702 | 68 | ET | S&D | DQ | 715.8 |
| 95 | 5702 | 4 | ET | S&D | UNK | 6.1 |
| 95 | 5709 | 101 | ET | S&D | DQ | 188.8 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 95 | 5146 | 95 | E | 3C | GSS | 3000 |
| 95 | 5146 | 60 | E | 3C | UNK | 233 |
| 95 | 5149 | 167 | E | S&D | DQ | 118.6 |
| 95 | 5149 | 168 | E | S&D | PAB | 276 |
| 95 | 5150 | 32 | E | 3C | DQ | 83.3 |
| 95 | 5150 | 33 | E | 3C | DQ | 34.4 |
| 95 | 5150 | 1 | E | 3C | PAB | 186.5 |
| 95 | 5151 | 1 | E | 3C | DQ | 196.2 |
| 95 | 5152 | 23 | E | 3C | KH | 602.2 |
| 95 | 5153 | 3 | E | 3C | DQ | 37 |
| 95 | 5153 | 2 | E | 3C | UNK | 323.3 |
| 95 | 5153 | 4 | E | 3C | UNK | 49.6 |
| 95 | 5171 | 1 | E | 3C | PAB | 45 |
| 95 | 5175 | 4 | E | 3C | PAB | 329.9 |
| 95 | 5176 | 1 | E | 3C | PAB | 312.9 |
| 95 | 5181 | 1 | E | 3C | DQ | 545.4 |
| 95 | 5181 | 2 | E | 3C | UNK | 203.1 |
| 95 | 5184 | 24 | E | 3C | PAB | 255 |
| 95 | 5184 | 3 | E | 3C | UNK | 70 |
| 95 | 5188 | 9 | E | 3C | UNK | 1133 |
| 95 | 5195 | 5 | E | 3C | PAB | 282 |
| 95 | 5711 | 30 | ET | 3C | KH | 9.2 |
| 95 | 5711 | 31 | ET | 3C | KH | 6.6 |
| 95 | 5711 | 33 | ET | 3C | KH | 34 |
| 95 | 5712 | 79 | ET | S&D | UNK | 366.1 |
| 95 | 5713 | 118 | ET | S&D | DQ | 240 |
| 95 | 5713 | 70 | ET | S&D | GSS | 193.6 |
| 95 | 5714 | 11 | ET | 3C | DQ | 16 |
| 95 | 5718 | 58 | ET | S&D | UNK | 64 |
| 95 | 5720 | 7 | ET | 3C | UNK | 75.9 |
| 95 | 5720 | 50 | ET | 3C | UNK | 56.3 |
| 95 | 5723 | 10 | ET | 3C | DQ | 129 |
| 95 | 5724 | 49 | ET | 3C | DQ | 143.8 |
| 95 | 5726 | 80 | ET | 3C | DQ | 34.1 |
| 95 | 5726 | 15 | ET | 3C | PAB | 797.1 |
| 95 | 5728 | 58 | ET | 3C | DQ | 34.1 |
| 95 | 5728 | 59 | ET | 3C | DQ | 14 |
| 95 | 5728 | 10 | ET | 3C | KH | 87.4 |
| 95 | 5729 | 220 | ET | 3C | DQ | 90.5 |
| 95 | 5729 | 74 | ET | 3C | PAB | 193 |
| 95 | 5729 | 78 | ET | 3C | PAB | 82 |
| 95 | 5732 | 23 | ET | 3C | DQ | 193.8 |
| 95 | 5735 | 74 | ET | S&D | PAB | 444 |
| 95 | 5735 | 75 | ET | S&D | UNK | 278 |
| 95 | 5737 | 21 | ET | 3C | DQ | 33 |
| 95 | 5740 | 23 | ET | 3C | DQ | 104.3 |
| 95 | 5740 | 24 | ET | 3C | PAB | 359 |
| 95 | 5741 | 45 | ET | 3C | DQ | 71 |
| 95 | 5741 | 46 | ET | 3C | DQ | 9 |
| 95 | 5741 | 47 | ET | 3C | GSS | 116 |
| 95 | 5741 | 49 | ET | 3C | PAB | 150 |
| 95 | 5741 | 50 | ET | 3C | UNK | 586 |
| 95 | 5743 | 13 | ET | 3C | DQ | 135.6 |
| 95 | 5745 | 16 | ET | S&D | DQ | 135 |
| 95 | 5745 | 1 | ET | S&D | UNK | 144 |
| 95 | 5745 | 3 | ET | S&D | UNK | 170 |
| 95 | 5745 | 17 | ET | S&D | UNK | 105.2 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 95 | 5709 | 112 | ET | S&D | DQ | 90.4 |
| 95 | 5709 | 100 | ET | S&D | GSS | 490.7 |
| 95 | 5709 | 102 | ET | S&D | UNK | 443.7 |
| 95 | 5709 | 113 | ET | S&D | UNK | 623 |
| 95 | 5710 | 77 | ET | S&D | DQ | 19.5 |
| 95 | 5710 | 78 | ET | S&D | DQ | 6.7 |
| 95 | 5710 | 79 | ET | S&D | PAB | 166 |
| 95 | 5711 | 32 | ET | 3C | DQ | 4 |
| 95 | 5711 | 29 | ET | 3C | KH | 9 |
| 95 | 5751 | 98 | ET | 3C | UNK | 83.7 |
| 95 | 5753 | 56 | ET | 3C | DQ | 18.3 |
| 95 | 5753 | 57 | ET | 3C | DQ | 61 |
| 95 | 5757 | 24 | ET | 3C | PAB | 209.8 |
| 95 | 5759 | 24 | ET | 3C | UNK | 279.5 |
| 95 | 5760 | 52 | ET | 3C | DQ | 6.5 |
| 95 | 5760 | 50 | ET | 3C | GSS | 90.4 |
| 95 | 5760 | 53 | ET | 3C | KH | 6.4 |
| 95 | 5760 | 18 | ET | 3C | UNK | 283.2 |
| 95 | 5762 | 1 | ET | 3C | DQ | 289.9 |
| 95 | 5764 | 2 | ET | 3C | DQ | 59.6 |
| 95 | 5764 | 73 | ET | 3C | DQ | 44.8 |
| 95 | 5767 | 1 | ET | 3C | PAB | 41.5 |
| 95 | 5778 | 1 | ET | 3C | PAB | 137.7 |
| 95 | 5778 | 1 | ET | 3C | PAB | 483.7 |
| 95 | 5789 | 7 | ET | 3C | DQ | 586.5 |
| 95 | 5802 | 1 | ET | 3C | PAB | 50.5 |
| 95 | 5802 | 8 | ET | 3C | PAB | 163.1 |
| 95 | 5802 | 172 | ET | 3C | PAB | 214.8 |
| 95 | 5802 | 134 | ET | 3C | UNK | 40 |
| 95 | 5807 | 56 | ET | 3C | DQ | 35.5 |
| 95 | 5807 | 264 | ET | 3C | DQ | 2400 |
| 95 | 5807 | 265 | ET | 3C | KH | 11.5 |
| 95 | 5807 | 54 | ET | 3C | PAB | 229.6 |
| 95 | 5807 | 58 | ET | 3C | PAB | 304 |
| 95 | 5807 | 57 | ET | 3C | UNK | 12.5 |
| 95 | 5807 | 263 | ET | 3C | UNK | 56.1 |
| 95 | 5807 | 266 | ET | 3C | UNK | 17.5 |
| 95 | 5810 | 60 | ET | 3C | PAB | 140.3 |
| 96 | 5832 | 22 | ET | 3C | PAB | 238.6 |
| 96 | 5837 | 26 | ET | 3C | GSS | 139.8 |
| 96 | 5837 | 27 | ET | 3C | PAB | 302.6 |
| 96 | 5837 | 25 | ET | 3C | UNK | 222.5 |
| 96 | 5840 | 5 | ET | 3C | PAB | 199.7 |
| 96 | 5851 | 2 | ET | 3C | PAB | 1282 |
| 95 | 5855 | 12 | ET | 3C | PAB | 4500 |
| 95 | 5856 | 1 | ET | 3C | UNK | 82.9 |
| 96 | 5860 | 5 | ET | 3C | PAB | 789.8 |
| 96 | 5863 | 2 | ET | 3C | GSS | 133 |
| 95 | 5868 | 25 | ET | 3C | PAB | 576.5 |
| 95 | 5872 | 1 | ET | 3C | PAB | 1123 |
| 95 | 5876 | 1 | ET | 3C | DQ | 2569 |
| 95 | 5900 | 41 | ET | 3C | PAB | 506.5 |
| 95 | 5902 | 8 | ET | 3C | GSS | 1082 |
| 95 | 5902 | 9 | ET | 3C | PAB | 1141 |
| 96 | 6351 | 5 | ET | 3C | GSS | 876.5 |
| 96 | 6351 | 6 | ET | 3C | UNK | 817.2 |
| 95 | 6503 | 32 | ET | 3C | PAB | 694 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 95 | 5746 | 89 | ET | 3C | DQ | 23 |
| 95 | 5746 | 88 | ET | 3C | UNK | 51 |
| 95 | 5747 | 12 | ET | 3C | DQ | 159 |
| 95 | 5749 | 10 | ET | 3C | DQ | 821.5 |
| 95 | 5749 | 11 | ET | 3C | DQ | 121.3 |
| 95 | 5749 | 12 | ET | 3C | DQ | 39.4 |
| 95 | 5750 | 32 | ET | 3C | DQ | 634.8 |
| 95 | 5750 | 1 | ET | 3C | KH | 105.3 |
| 95 | 5751 | 30 | ET | 3C | DQ | 86.1 |
| 94 | 6009 | 1 | F | S&D | DQ | 338.3 |
| 96 | 6199 | 1 | n/a | n/a | GSS | 152.1 |
| 96 | 6201 | 1 | ET | S&D | DQ | 1741 |
| 96 | 6201 | 2 | ET | S&D | GSS | 385 |
| 96 | 6202 | 2 | ET | S&D | DQ | 1132 |
| 96 | 6202 | 3 | ET | S&D | GSS | 118.7 |
| 96 | 6211 | 34 | ET | S&D | UNK | 31.5 |
| 96 | 6219 | 66 | ET | S&D | DQ | 929 |
| 96 | 6219 | 85 | ET | S&D | GSS | 48.3 |
| 96 | 6219 | 88 | ET | S&D | PAB | 405 |
| 96 | 6220 | 9 | ET | S&D | DQ | 266.3 |
| 96 | 6220 | 10 | ET | S&D | UNK | 329.5 |
| 96 | 6222 | 62 | ET | S&D | UNK | 267.5 |
| 96 | 6223 | 29 | ET | 3C | DQ | 57.3 |
| 96 | 6223 | 28 | ET | 3C | UNK | 140 |
| 96 | 6224 | 45 | ET | S&D | DQ | 161.3 |
| 96 | 6224 | 44 | ET | S&D | UNK | 83 |
| 96 | 6226 | 9 | ET | 3C | DQ | 60.5 |
| 96 | 6226 | 8 | ET | 3C | UNK | 268.4 |
| 96 | 6230 | 13 | ET | 3C | GSS | 303.3 |
| 96 | 6231 | 83 | ET | S&D | DQ | 11.4 |
| 96 | 6234 | 10 | ET | S&D | DQ | 386.7 |
| 96 | 6234 | 11 | ET | S&D | UNK | 275.3 |
| 96 | 6237 | 2 | ET | 3C | DQ | 124.5 |
| 96 | 6237 | 1 | ET | 3C | UNK | 161.5 |
| 96 | 6239 | 1 | ET | S&D | PAB | 351.1 |
| 96 | 6239 | 2 | ET | S&D | UNK | 10.1 |
| 96 | 6244 | 56 | ET | S&D | DQ | 41.7 |
| 96 | 6244 | 55 | ET | S&D | GSS | 93.8 |
| 96 | 6244 | 2 | ET | S&D | PAB | 575 |
| 96 | 6251 | 1 | ET | 3C | DQ | 228.8 |
| 96 | 6251 | 18 | ET | 3C | DQ | 564.3 |
| 96 | 6251 | 2 | ET | 3C | UNK | 84.4 |
| 96 | 6251 | 4 | ET | 3C | UNK | 146 |
| 96 | 6251 | 25 | ET | 3C | UNK | 4.5 |
| 96 | 6251 | 26 | ET | 3C | UNK | 16.7 |
| 96 | 6254 | 2 | ET | 3C | KH | 130 |
| 96 | 6255 | 2 | ET | 3C | PAB | 268.5 |
| 96 | 6255 | 3 | ET | 3C | PAB | 143.3 |
| 96 | 6255 | 1 | ET | 3C | UNK | 379 |
| 96 | 6256 | 1 | ET | 3C | GSS | 656 |
| 96 | 6257 | 1 | ET | 3C | PAB | 810.3 |
| 96 | 6300 | 22 | ET | S&D | GSS | 181 |
| 96 | 6303 | 73 | ET | S&D | GSS | 103.2 |
| 96 | 6310 | 153 | ET | 3C | UNK | 44.4 |
| 95 | 7013 | 1 | AB | S&D | DQ | 1081 |
| 95 | 7015 | 1 | AB | 3C | PAB | 623.6 |
| 95 | 7015 | 2 | AB | 3C | UNK | 350 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 95 | 6503 | 67 | ET | 3C | PAB | 75.6 |
| 95 | 6512 | 29 | ET | 2 | PAB | 257.6 |
| 95 | 6525 | 13 | ET | 3C | DQ | 42.1 |
| 95 | 6525 | 24 | ET | 3C | PAB | 217.4 |
| 95 | 6527 | 1 | ET | 2 | PAB | 157.2 |
| 95 | 6532 | 8 | ET | 2 | PAB | 143.2 |
| 95 | 6538 | 38 | ET | 2 | KH | 38.4 |
| 95 | 6547 | 3 | ET | 3C | DQ | 105 |
| 95 | 6605 | 2 | ET | 3C | UNK | 61.3 |
| 95 | 6612 | 1 | ET | 3C | GSS | 171.7 |
| 95 | 6619 | 1 | ET | 3C | PAB | 530.5 |
| 97 | 6645 | 5 | ET | 3B | PAB | 383.5 |
| 97 | 6686 | 17 | ET | 3B | PAB | 253.3 |
| 95 | 6703 | 2 | E | 3C | DQ | 80 |
| 95 | 6703 | 1 | E | 3C | UNK | 106.3 |
| 95 | 6716 | 1 | E | 3C | UNK | 129 |
| 95 | 6716 | 2 | E | 3C | UNK | 80 |
| 96 | 6821 | 18 | E | S&D | KH | 2992 |
| 96 | 6821 | 128 | E | S&D | UNK | 458 |
| 96 | 6821 | 135 | E | S&D | UNK | 39.7 |
| 96 | 6838 | 2 | E | 3C | GSS | 207 |
| 96 | 6838 | 38 | E | 3C | PAB | 191.8 |
| 96 | 6838 | 39 | E | 3C | PAB | 198.5 |
| 96 | 6862 | 23 | E | 3C | UNK | 214 |
| 96 | 6864 | 25 | E | 3C | PAB | 654.8 |
| 96 | 6868 | 28 | E | 3C | DQ | 121.7 |
| 96 | 6868 | 35 | E | 3C | PAB | 972.4 |
| 96 | 6876 | 25 | E | 3C | GSS | 23.5 |
| 96 | 6882 | 14 | E | 3C | PAB | 766.1 |
| 96 | 6884 | 9 | E | 3C | PAB | 266 |
| 96 | 6912 | 10 | E | 3C | UNK | 450 |
| 96 | 6923 | 7 | E | 3C | PAB | 254.3 |
| 96 | 6963 | 15 | E | 3C | DQ | 318.1 |
| 96 | 6972 | 3 | E | 3C | PAB | 669 |
| 96 | 6972 | 4 | E | 3C | PAB | 261.8 |
| 97 | 6989 | 15 | E | S&D | UNK | 309.5 |
| 97 | 6989 | 16 | E | S&D | UNK | 190.5 |
| 95 | 7000 | 11 | AB | S&D | UNK | 297.5 |
| 95 | 7002 | 12 | AB | S&D | PAB | 749.3 |
| 95 | 7003 | 17 | AB | S&D | KH | 27.5 |
| 95 | 7004 | 14 | AB | S&D | DQ | 158.7 |
| 95 | 7004 | 12 | AB | S&D | UNK | 18.7 |
| 96 | 7232 | 46 | F | 3C | PAB | 73.9 |
| 96 | 7243 | 26 | F | S&D | UNK | 2.5 |
| 96 | 7243 | 69 | F | S&D | UNK | 219 |
| 96 | 7248 | 2 | F | 3C | PAB | 79.3 |
| 96 | 7254 | 53 | F | 3B | PAB | 365.2 |
| 96 | 7256 | 41 | F | 3B | PAB | 43.4 |
| 96 | 7257 | 54 | F | 3B | KH | 211.5 |
| 96 | 7257 | 52 | F | 3B | UNK | 187.9 |
| 96 | 7257 | 53 | F | 3B | UNK | 209.9 |
| 96 | 7257 | 55 | F | 3B | UNK | 69.5 |
| 96 | 7263 | 6 | F | 3C | UNK | 1118 |
| 96 | 7291 | 1 | F | 3B | PAB | 294.5 |
| 96 | 7310 | 17 | AB | 5 | DQ | 3 |
| 96 | 7317 | 1 | AB | 5 | UNK | 659.2 |
| 96 | 7319 | 1 | AB | 4 | KH | 347.2 |
| 96 | 7329 | 3 | AB | 5 | UNK | 121.2 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 95 | 7016 | 11 | AB | 3C | UNK | 42.9 |
| 96 | 7101 | 13 | E | S&D | DQ | 14.4 |
| 96 | 7103 | 11 | E | S&D | GSS | 9.2 |
| 96 | 7103 | 12 | E | S&D | PAB | 91.5 |
| 96 | 7103 | 13 | E | S&D | PAB | 117.3 |
| 96 | 7103 | 24 | E | S&D | PAB | 201.7 |
| 96 | 7103 | 14 | E | S&D | UNK | 225.5 |
| 96 | 7103 | 15 | E | S&D | UNK | 50.8 |
| 96 | 7104 | 139 | E | S&D | UNK | 59 |
| 96 | 7109 | 1 | E | 3C | KH | 1161 |
| 96 | 7113 | 3 | E | S&D | DQ | 120.2 |
| 96 | 7113 | 4 | E | S&D | GSS | 18.5 |
| 96 | 7114 | 1 | E | S&D | DQ | 230.6 |
| 96 | 7114 | 4 | E | S&D | UNK | 416.3 |
| 96 | 7115 | 15 | E | 3C | DQ | 251.7 |
| 96 | 7115 | 14 | E | 3C | PAB | 214 |
| 96 | 7115 | 13 | E | 3C | UNK | 143 |
| 96 | 7118 | 53 | E | 3C | UNK | 2.6 |
| 96 | 7121 | 84 | E | 3C | UNK | 7.3 |
| 96 | 7123 | 5 | E | 3C | PAB | 623.6 |
| 96 | 7123 | 4 | E | 3C | UNK | 144.3 |
| 96 | 7144 | 7 | E | 3C | PAB | 165.3 |
| 96 | 7148 | 43 | E | 3C | UNK | 89.5 |
| 96 | 7149 | 78 | E | S&D | UNK | 15.5 |
| 96 | 7150 | 6 | E | S&D | DQ | 261.7 |
| 96 | 7150 | 22 | E | S&D | DQ | 22.9 |
| 96 | 7155 | 9 | E | 3C | UNK | 13.2 |
| 96 | 7156 | 19 | E | 3C | UNK | 76.6 |
| 96 | 7201 | 12 | F | S&D | UNK | 3189 |
| 96 | 7202 | 5 | F | S&D | DQ | 151.3 |
| 96 | 7203 | 8 | F | S&D | DQ | 198 |
| 96 | 7205 | 2 | F | S&D | DQ | 1850 |
| 96 | 7205 | 11 | F | S&D | DQ | 1954 |
| 96 | 7209 | 40 | F | S&D | GSS | 189.7 |
| 96 | 7210 | 14 | F | S&D | UNK | 219.8 |
| 96 | 7212 | 4 | F | S&D | PAB | 295.2 |
| 96 | 7218 | 6 | F | S&D | KH | 25.2 |
| 96 | 7227 | 34 | F | 3C | DQ | 111 |
| 96 | 7227 | 35 | F | 3C | PAB | 362.1 |
| 96 | 7229 | 5 | F | 3C | UNK | 27.8 |
| 96 | 7230 | 2 | F | S&D | DQ | 917.2 |
| 96 | 7230 | 34 | F | S&D | DQ | 152.9 |
| 96 | 7466 | 13 | AB | 2 | KH | 3600 |
| 96 | 7467 | 297 | AB | 3A | KH | 682.4 |
| 96 | 7467 | 298 | AB | 3A | KH | 976 |
| 96 | 7467 | 299 | AB | 3A | KH | 1146 |
| 96 | 7467 | 302 | AB | 3A | UNK | 127.5 |
| 96 | 7482 | 1 | AB | 2 | KH | 168.9 |
| 96 | 7482 | 5 | AB | 2 | KH | 153.4 |
| 96 | 7490 | 39 | AB | 2 | KH | 4.5 |
| 96 | 7490 | 40 | AB | 2 | KH | 5 |
| 96 | 7490 | 38 | AB | 2 | UNK | 25 |
| 96 | 7491 | 7 | AB | 1 | KH | 99.7 |
| 96 | 7491 | 9 | AB | 1 | UNK | 1 |
| 96 | 7492 | 4 | AB | 1 | KH | 32.9 |
| 96 | 7492 | 5 | AB | 1 | KH | 20 |
| 96 | 7493 | 5 | AB | 1 | KH | 81 |
| 96 | 7493 | 4 | AB | 1 | UNK | 259 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 96 | 7333 | 28 | AB | 5 | GSS | 10.7 |
| 96 | 7333 | 31 | AB | 5 | PAB | 184.9 |
| 96 | 7344 | 1 | AB | 5 | DQ | 10.9 |
| 96 | 7351 | 9 | AB | 5 | UNK | 4 |
| 96 | 7355 | 9 | AB | 5 | DQ | 53.5 |
| 96 | 7356 | 57 | AB | 4 | DQ | 24.5 |
| 96 | 7356 | 61 | AB | 4 | DQ | 70 |
| 96 | 7356 | 60 | AB | 4 | GSS | 122.5 |
| 96 | 7356 | 54 | AB | 4 | PAB | 72.2 |
| 96 | 7356 | 58 | AB | 4 | UNK | 18.8 |
| 96 | 7357 | 4 | AB | 5 | DQ | 666.3 |
| 96 | 7357 | 2 | AB | 5 | UNK | 251.6 |
| 96 | 7359 | 6 | AB | 4 | KH | 164.8 |
| 96 | 7373 | 3 | AB | 4 | UNK | 80 |
| 96 | 7375 | 15 | AB | 4 | DQ | 160.3 |
| 96 | 7375 | 8 | AB | 4 | UNK | 47.8 |
| 96 | 7401 | 19 | AB | 3A | UNK | 228.8 |
| 96 | 7402 | 88 | AB | 3A | PAB | 1160 |
| 96 | 7403 | 6 | AB | 3A | PAB | 253 |
| 96 | 7419 | 35 | AB | 2 | KH | 29.8 |
| 96 | 7423 | 84 | AB | 2 | KH | 39 |
| 96 | 7423 | 3 | AB | 2 | UNK | 114.5 |
| 96 | 7423 | 93 | AB | 2 | UNK | 12.3 |
| 96 | 7431 | 9 | AB | 2 | UNK | 400 |
| 96 | 7451 | 2 | AB | S&D | PAB | 44.5 |
| 96 | 7460 | 8 | AB | 2 | KH | 253.8 |
| 96 | 7460 | 7 | AB | 2 | UNK | 242.1 |
| 96 | 7460 | 48 | AB | 2 | UNK | 4.5 |
| 96 | 7462 | 6 | AB | 2 | KH | 1321 |
| 99 | 7631 | 16 | F | 3C | UNK | 174 |
| 99 | 7631 | 17 | F | 3C | UNK | 151 |
| 99 | 7631 | 28 | F | 3C | UNK | 53.3 |
| 99 | 7633 | 8 | F | 3C | DQ | 892.8 |
| 99 | 7633 | 9 | F | 3C | PAB | 289 |
| 99 | 7635 | 15 | F | 3C | UNK | 216.4 |
| 99 | 7635 | 56 | F | 3C | UNK | 477 |
| 99 | 7643 | 5 | F | 3C | DQ | 255.6 |
| 99 | 7643 | 4 | F | 3C | PAB | 218.4 |
| 99 | 7647 | 1 | F | 3C | GSS | 800.9 |
| 99 | 7648 | 2 | F | 3C | UNK | 950.4 |
| 99 | 7666 | 7 | F | S&D | DQ | 2270 |
| 99 | 7666 | 8 | F | S&D | DQ | 2690 |
| 99 | 7666 | 9 | F | S&D | DQ | 1696 |
| 99 | 7666 | 24 | F | S&D | DQ | 1266 |
| 99 | 7666 | 25 | F | S&D | DQ | 657 |
| 99 | 7666 | 5 | F | S&D | GSS | 1013 |
| 99 | 7666 | 16 | F | S&D | GSS | 311.5 |
| 99 | 7666 | 28 | F | S&D | GSS | 763 |
| 99 | 7666 | 17 | F | S&D | KH | 185.7 |
| 99 | 7666 | 10 | F | S&D | PAB | 1866 |
| 99 | 7666 | 12 | F | S&D | PAB | 588 |
| 99 | 7666 | 15 | F | S&D | PAB | 375 |
| 99 | 7666 | 22 | F | S&D | PAB | 1341 |
| 99 | 7666 | 23 | F | S&D | PAB | 1158 |
| 99 | 7666 | 26 | F | S&D | PAB | 1161 |
| 99 | 7666 | 6 | F | S&D | UNK | 571.1 |
| 99 | 7666 | 11 | F | S&D | UNK | 370.5 |
| 99 | 7666 | 13 | F | S&D | UNK | 1016 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 96 | 7495 | 10 | AB | 1 | KH | 72.5 |
| 96 | 7496 | 13 | AB | 1 | KH | 119.9 |
| 96 | 7496 | 14 | AB | 1 | KH | 68.3 |
| 96 | 7497 | 17 | AB | 1 | KH | 287.5 |
| 96 | 7498 | 4 | AB | 1 | KH | 2750 |
| 96 | 7498 | 5 | AB | 1 | KH | 153 |
| 96 | 7500 | 25 | AB | 1 | KH | 31.9 |
| 96 | 7503 | 2 | AB | 1 | KH | 189.9 |
| 96 | 7512 | 161 | AB | 1 | KH | 346.5 |
| 97 | 7603 | 1 | F | 3C | PAB | 430 |
| 97 | 7607 | 26 | F | 3C | GSS | 15.2 |
| 97 | 7608 | 1 | F | 3C | DQ | 2595 |
| 97 | 7608 | 2 | F | 3C | PAB | 111.2 |
| 97 | 7617 | 10 | F | 3C | PAB | 467 |
| 97 | 7617 | 11 | F | 3C | UNK | 57 |
| 97 | 7619 | 19 | F | 3C | DQ | 22.1 |
| 99 | 7631 | 4 | F | 3C | DQ | 913.5 |
| 99 | 7631 | 5 | F | 3C | DQ | 176.5 |
| 99 | 7631 | 6 | F | 3C | DQ | 128.5 |
| 99 | 7631 | 9 | F | 3C | DQ | 2500 |
| 99 | 7631 | 11 | F | 3C | DQ | 1262 |
| 99 | 7631 | 13 | F | 3C | DQ | 466 |
| 99 | 7631 | 18 | F | 3C | DQ | 84 |
| 99 | 7631 | 15 | F | 3C | GSS | 330 |
| 99 | 7631 | 3 | F | 3C | PAB | 1258 |
| 99 | 7631 | 8 | F | 3C | PAB | 3500 |
| 99 | 7631 | 12 | F | 3C | PAB | 874 |
| 99 | 7631 | 10 | F | 3C | UNK | 1409 |
| 99 | 7631 | 14 | F | 3C | UNK | 422 |
| 99 | 7792 | 5 | AB | 3C | UNK | 91.5 |
| 99 | 7793 | 1 | AB | 3C | PAB | 50.2 |
| 99 | 7798 | 4 | AB | 3C | DQ | 20 |
| 99 | 7798 | 3 | AB | 3C | KH | 68.3 |
| 97 | 7814 | 8 | ET | S&D | PAB | 1016 |
| 97 | 7816 | 1 | ET | S&D | PAB | 252.5 |
| 97 | 7817 | 1 | ET | S&D | DQ | 498 |
| 97 | 7817 | 1 | ET | S&D | UNK | 332 |
| 97 | 7819 | 21 | ET | 3B | DQ | 290 |
| 97 | 7819 | 2 | ET | 3B | PAB | 326 |
| 97 | 7824 | 52 | ET | 3B | UNK | 104.6 |
| 97 | 7825 | 8 | ET | 3B | PAB | 9000 |
| 97 | 7835 | 1 | ET | 3B | PAB | 348.8 |
| 97 | 7844 | 1 | ET | S&D | PAB | 115.7 |
| 97 | 7851 | 20 | ET | 3B | PAB | 1170 |
| 97 | 8025 | 4 | E | 3B | KH | 26.6 |
| 97 | 8053 | 21 | E | 3C | UNK | 428.2 |
| 97 | 8081 | 3 | E | 3C | PAB | 408.7 |
| 97 | 8105 | 6 | E | S&D | PAB | 384 |
| 97 | 8107 | 12 | E | 3C | PAB | 250.9 |
| 97 | 8107 | 13 | E | 3C | PAB | 580.4 |
| 97 | 8107 | 22 | E | 3C | PAB | 1040 |
| 97 | 8107 | 55 | E | 3C | PAB | 311 |
| 97 | 8108 | 1 | E | 3C | PAB | 1277 |
| 97 | 8109 | 1 | E | S&D | DQ | 400 |
| 97 | 8110 | 3 | E | S&D | PAB | 353.6 |
| 97 | 8110 | 4 | E | S&D | PAB | 322.4 |
| 97 | 8111 | 33 | E | 3C | DQ | 362.1 |
| 97 | 8111 | 34 | E | 3C | UNK | 105.7 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 99 | 7666 | 14 | F | S&D | UNK | 133 |
| 99 | 7666 | 20 | F | S&D | UNK | 1202 |
| 99 | 7666 | 21 | F | S&D | UNK | 809.8 |
| 99 | 7666 | 27 | F | S&D | UNK | 590.8 |
| 99 | 7666 | 35 | F | S&D | UNK | 518.8 |
| 98 | 7680 | 3 | F | 3C | PAB | 300 |
| 97 | 7701 | 182 | AB | 3C | GSS | 182 |
| 97 | 7715 | 6 | AB | S&D | UNK | 308 |
| 97 | 7715 | 10 | AB | S&D | UNK | 7000 |
| 97 | 7740 | 3 | AB | S&D | DQ | 231.2 |
| 97 | 7743 | 1 | AB | S&D | PAB | 80.9 |
| 97 | 7781 | 24 | AB | S&D | PAB | 157.3 |
| 97 | 7784 | 804 | AB | S&D | UNK | 111.9 |
| 99 | 7790 | 2 | AB | 3C | UNK | 95.4 |
| 99 | 7790 | 15 | AB | 3C | UNK | 202.2 |
| 99 | 7791 | 8 | AB | 3C | UNK | 250.3 |
| 98 | 8161 | 49 | E | 3C | DQ | 784.1 |
| 98 | 8161 | 23 | E | 3C | UNK | 165.2 |
| 98 | 8163 | 11 | E | 3C | PAB | 499.5 |
| 98 | 8163 | 12 | E | 3C | PAB | 67.5 |
| 98 | 8163 | 8 | E | 3C | UNK | 317.5 |
| 98 | 8165 | 17 | E | S&D | PAB | 730 |
| 98 | 8165 | 32 | E | S&D | PAB | 1247 |
| 98 | 8165 | 104 | E | S&D | PAB | 207 |
| 98 | 8165 | 105 | E | S&D | PAB | 558.8 |
| 98 | 8165 | 126 | E | S&D | PAB | 379.7 |
| 98 | 8165 | 16 | E | S&D | UNK | 53.9 |
| 98 | 8165 | 33 | E | S&D | UNK | 1204 |
| 98 | 8165 | 99 | E | S&D | UNK | 93.5 |
| 98 | 8165 | 100 | E | S&D | UNK | 136.1 |
| 98 | 8165 | 101 | E | S&D | UNK | 73 |
| 98 | 8165 | 103 | E | S&D | UNK | 260.4 |
| 98 | 8165 | 124 | E | S&D | UNK | 260.9 |
| 98 | 8166 | 12 | E | S&D | PAB | 449.4 |
| 98 | 8166 | 13 | E | S&D | UNK | 173 |
| 98 | 8167 | 4 | E | 3C | PAB | 116.6 |
| 98 | 8169 | 97 | E | 3C | PAB | 468.7 |
| 98 | 8170 | 20 | E | 3C | UNK | 27.5 |
| 98 | 8170 | 21 | E | 3C | UNK | 114 |
| 98 | 8172 | 24 | E | S&D | UNK | 127.6 |
| 98 | 8173 | 40 | E | S&D | DQ | 544 |
| 98 | 8173 | 42 | E | S&D | DQ | 173.5 |
| 98 | 8173 | 90 | E | S&D | DQ | 159.7 |
| 98 | 8173 | 91 | E | S&D | DQ | 105.7 |
| 98 | 8173 | 92 | E | S&D | DQ | 47.8 |
| 98 | 8173 | 39 | E | S&D | GSS | 269.6 |
| 98 | 8173 | 41 | E | S&D | PAB | 782.3 |
| 98 | 8173 | 99 | E | S&D | UNK | 300 |
| 98 | 8173 | 99 | E | S&D | UNK | 313 |
| 98 | 8175 | 13 | E | 3C | PAB | 121.5 |
| 98 | 8175 | 14 | E | 3C | PAB | 105.9 |
| 98 | 8176 | 111 | E | 3C | DQ | 260 |
| 98 | 8176 | 25 | E | 3C | PAB | 576 |
| 98 | 8176 | 26 | E | 3C | UNK | 49.8 |
| 98 | 8176 | 45 | E | 3C | UNK | 274.9 |
| 98 | 8183 | 15 | E | 3C | UNK | 339.7 |
| 98 | 8183 | 16 | E | 3C | UNK | 137.1 |
| 98 | 8185 | 8 | E | 3C | PAB | 281.2 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 97 | 8113 | 4 | E | 3C | DQ | 66.6 |
| 97 | 8113 | 3 | E | 3C | PAB | 151 |
| 97 | 8115 | 14 | E | 3C | DQ | 1057 |
| 97 | 8115 | 13 | E | 3C | GSS | 405.8 |
| 97 | 8115 | 15 | E | 3C | PAB | 1478 |
| 97 | 8115 | 40 | E | 3C | UNK | 142.3 |
| 97 | 8121 | 4 | E | 3C | PAB | 1700 |
| 98 | 8154 | 12 | E | 3C | DQ | 81.7 |
| 98 | 8154 | 11 | E | 3C | UNK | 188.9 |
| 98 | 8158 | 44 | E | 3C | DQ | 470 |
| 98 | 8158 | 75 | E | 3C | DQ | 600.1 |
| 98 | 8158 | 3 | E | 3C | PAB | 346.1 |
| 98 | 8158 | 63 | E | 3C | UNK | 127.7 |
| 98 | 8158 | 79 | E | 3C | UNK | 195.9 |
| 98 | 8159 | 36 | E | 3C | DQ | 181.5 |
| 98 | 8159 | 37 | E | 3C | PAB | 243.3 |
| 97 | 8201 | 4 | E | 3B | GSS | 761.5 |
| 97 | 8245 | 1 | E | 3C | PAB | 1260 |
| 98 | 8301 | 81 | AB | S&D | GSS | 277 |
| 98 | 8301 | 64 | AB | S&D | KH | 199.5 |
| 98 | 8301 | 66 | AB | S&D | UNK | 300 |
| 98 | 8301 | 163 | AB | S&D | UNK | 200 |
| 98 | 8302 | 36 | AB | S&D | PAB | 58.2 |
| 98 | 8302 | 35 | AB | S&D | UNK | 185.3 |
| 98 | 8303 | 37 | AB | S&D | UNK | 47.7 |
| 98 | 8303 | 39 | AB | S&D | UNK | 5.4 |
| 98 | 8304 | 2 | AB | S&D | KH | 116.1 |
| 98 | 8305 | 82 | AB | S&D | DQ | 1.2 |
| 98 | 8305 | 10 | AB | S&D | KH | 1.25 |
| 98 | 8305 | 8 | AB | S&D | UNK | 82.9 |
| 98 | 8305 | 9 | AB | S&D | UNK | 386.8 |
| 98 | 8305 | 65 | AB | S&D | UNK | 120.3 |
| 98 | 8305 | 81 | AB | S&D | UNK | 1.9 |
| 98 | 8306 | 26 | AB | S&D | DQ | 565.3 |
| 98 | 8306 | 262 | AB | S&D | DQ | 151.6 |
| 98 | 8306 | 84 | AB | S&D | GSS | 150.9 |
| 98 | 8306 | 198 | AB | S&D | GSS | 32.4 |
| 98 | 8306 | 221 | AB | S&D | KH | 363 |
| 98 | 8306 | 27 | AB | S&D | UNK | 334.6 |
| 98 | 8306 | 167 | AB | S&D | UNK | 249.5 |
| 98 | 8306 | 219 | AB | S&D | UNK | 208.2 |
| 98 | 8306 | 261 | AB | S&D | UNK | 75.7 |
| 98 | 8306 | 262 | AB | S&D | UNK | 105.9 |
| 98 | 8306 | 263 | AB | S&D | UNK | 137.3 |
| 98 | 8308 | 57 | AB | 3C | DQ | 232.1 |
| 98 | 8308 | 9 | AB | 3C | UNK | 93.1 |
| 98 | 8308 | 32 | AB | 3C | UNK | 1610 |
| 98 | 8309 | 1 | AB | 3C | GSS | 104.5 |
| 98 | 8310 | 110 | AB | 3C | DQ | 1.5 |
| 98 | 8310 | 127 | AB | 3C | UNK | 250.8 |
| 98 | 8310 | 154 | AB | 3C | UNK | 321.3 |
| 98 | 8311 | 7 | AB | 3C | KH | 38.2 |
| 98 | 8311 | 8 | AB | 3C | KH | 19.8 |
| 98 | 8313 | 159 | AB | S&D | DQ | 53.5 |
| 98 | 8314 | 16 | AB | 3C | KH | 19.5 |
| 98 | 8315 | 6 | AB | 3C | UNK | 332.2 |
| 98 | 8315 | 7 | AB | 3C | UNK | 140.8 |
| 98 | 8315 | 8 | AB | 3C | UNK | 57.1 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 98 | 8198 | 22 | E | 3C | DQ | 57.9 |
| 98 | 8198 | 23 | E | 3C | DQ | 373.3 |
| 98 | 8198 | 25 | E | 3C | DQ | 115.8 |
| 98 | 8322 | 126 | AB | 3C | KH | 77.8 |
| 98 | 8322 | 124 | AB | 3C | UNK | 20.2 |
| 98 | 8322 | 125 | AB | 3C | UNK | 7.7 |
| 98 | 8323 | 50 | AB | 3C | UNK | 89.4 |
| 98 | 8326 | 124 | AB | 3C | DQ | 186 |
| 98 | 8326 | 125 | AB | 3C | KH | 41.9 |
| 98 | 8328 | 23 | AB | 3C | DQ | 269.5 |
| 98 | 8331 | 73 | AB | S&D | DQ | 31 |
| 98 | 8331 | 37 | AB | S&D | UNK | 200 |
| 98 | 8332 | 15 | AB | S&D | DQ | 201 |
| 98 | 8332 | 3 | AB | S&D | KH | 557.9 |
| 98 | 8332 | 16 | AB | S&D | UNK | 100 |
| 98 | 8334 | 84 | AB | S&D | PAB | 138 |
| 98 | 8334 | 2 | AB | S&D | UNK | 3000 |
| 98 | 8334 | 6 | AB | S&D | UNK | 117.7 |
| 98 | 8334 | 7 | AB | S&D | UNK | 150.5 |
| 98 | 8336 | 87 | AB | 3C | GSS | 304.2 |
| 98 | 8340 | 13 | AB | 3C | GSS | 198.3 |
| 98 | 8341 | 44 | AB | 3C | DQ | 13.5 |
| 98 | 8341 | 53 | AB | 3C | DQ | 81.4 |
| 98 | 8341 | 54 | AB | 3C | DQ | 62.7 |
| 98 | 8347 | 129 | AB | 3C | DQ | 135.3 |
| 98 | 8366 | 12 | AB | 3B | PAB | 285.3 |
| 98 | 8375 | 74 | AB | 3B | UNK | 48.2 |
| 98 | 8377 | 6 | AB | 3B | UNK | 593.7 |
| 98 | 8380 | 3 | AB | 3C | KH | 6.9 |
| 99 | 8385 | 27 | AB | S&D | KH | 34.4 |
| 99 | 8387 | 110 | AB | S&D | UNK | 145 |
| 99 | 8388 | 133 | AB | S&D | PAB | 240.1 |
| 99 | 8388 | 120 | AB | S&D | UNK | 225.3 |
| 99 | 8388 | 121 | AB | S&D | UNK | 36 |
| 99 | 8393 | 140 | AB | 3C | GSS | 216.5 |
| 99 | 8394 | 22 | AB | S&D | DQ | 207 |
| 99 | 8394 | 45 | AB | S&D | PAB | 322 |
| 99 | 8394 | 24 | AB | S&D | UNK | 10.9 |
| 99 | 8394 | 33 | AB | S&D | UNK | 76.3 |
| 99 | 8394 | 44 | AB | S&D | UNK | 170.3 |
| 99 | 8394 | 46 | AB | S&D | UNK | 830 |
| 99 | 8395 | 58 | AB | S&D | UNK | 280.9 |
| 99 | 8395 | 73 | AB | S&D | UNK | 173.8 |
| 99 | 8395 | 74 | AB | S&D | UNK | 48.2 |
| 99 | 8398 | 16 | AB | 3B | KH | 154.5 |
| 98 | 8404 | 114 | AB | S&D | DQ | 234.7 |
| 98 | 8404 | 1083 | AB | S&D | DQ | 71.5 |
| 98 | 8404 | 1090 | AB | S&D | DQ | 59.5 |
| 98 | 8428 | 33 | AB | 2 | KH | 4.2 |
| 98 | 8429 | 19 | AB | 2 | KH | 82.2 |
| 98 | 8430 | 24 | AB | 2 | KH | 333.6 |
| 98 | 8430 | 25 | AB | 2 | KH | 143.7 |
| 98 | 8430 | 26 | AB | 2 | KH | 94.9 |
| 98 | 8430 | 27 | AB | 2 | KH | 40.9 |
| 98 | 8430 | 28 | AB | 2 | KH | 44.3 |
| 98 | 8430 | 23 | AB | 2 | UNK | 90 |
| 98 | 8430 | 59 | AB | 2 | UNK | 117.9 |
| 98 | 8431 | 5 | AB | 2 | KH | 102.7 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 98 | 8321 | 6 | AB | 3C | GSS | 235.5 |
| 98 | 8322 | 2 | AB | 3C | DQ | 125 |
| 98 | 8322 | 118 | AB | 3C | DQ | 377.2 |
| 98 | 8404 | 1091 | AB | S&D | DQ | 13.2 |
| 98 | 8404 | 1092 | AB | S&D | DQ | 12.4 |
| 98 | 8404 | 1096 | AB | S&D | DQ | 2.3 |
| 98 | 8404 | 1139 | AB | S&D | DQ | 545 |
| 98 | 8404 | 113 | AB | S&D | KH | 180.4 |
| 98 | 8404 | 115 | AB | S&D | KH | 129.7 |
| 98 | 8404 | 116 | AB | S&D | KH | 50 |
| 98 | 8404 | 120 | AB | S&D | KH | 322 |
| 98 | 8404 | 160 | AB | S&D | KH | 888.8 |
| 98 | 8404 | 356 | AB | S&D | KH | 1280 |
| 98 | 8404 | 1088 | AB | S&D | KH | 67.7 |
| 98 | 8404 | 1089 | AB | S&D | KH | 26.8 |
| 98 | 8404 | 1093 | AB | S&D | KH | 267 |
| 98 | 8404 | 1094 | AB | S&D | KH | 25.9 |
| 98 | 8404 | 1095 | AB | S&D | KH | 3.7 |
| 98 | 8404 | 1082 | AB | S&D | PAB | 370 |
| 98 | 8404 | 1084 | AB | S&D | PAB | 162.5 |
| 98 | 8404 | 1085 | AB | S&D | PAB | 73 |
| 98 | 8404 | 1087 | AB | S&D | PAB | 48.4 |
| 98 | 8404 | 117 | AB | S&D | UNK | 33.5 |
| 98 | 8404 | 119 | AB | S&D | UNK | 1006 |
| 98 | 8404 | 127 | AB | S&D | UNK | 393 |
| 98 | 8404 | 191 | AB | S&D | UNK | 450 |
| 98 | 8404 | 1086 | AB | S&D | UNK | 98.2 |
| 98 | 8404 | 1140 | AB | S&D | UNK | 423 |
| 98 | 8408 | 12 | AB | 2 | KH | 4.5 |
| 98 | 8409 | 48 | AB | 2 | KH | 182.9 |
| 98 | 8412 | 154 | AB | 3A | KH | 99.9 |
| 98 | 8412 | 260 | AB | 3A | KH | 39.7 |
| 98 | 8412 | 193 | AB | 3A | PAB | 75 |
| 98 | 8412 | 208 | AB | 3A | PAB | 156.3 |
| 98 | 8412 | 209 | AB | 3A | PAB | 720.7 |
| 98 | 8412 | 124 | AB | 3A | UNK | 65.1 |
| 98 | 8412 | 125 | AB | 3A | UNK | 131.5 |
| 98 | 8412 | 166 | AB | 3A | UNK | 750 |
| 98 | 8412 | 194 | AB | 3A | UNK | 157.7 |
| 98 | 8412 | 207 | AB | 3A | UNK | 72.3 |
| 98 | 8413 | 31 | AB | 2 | KH | 63.4 |
| 98 | 8416 | 2 | AB | 3A | UNK | 3.8 |
| 98 | 8416 | 11 | AB | 3A | UNK | 286.7 |
| 98 | 8424 | 13 | AB | 2 | KH | 31.5 |
| 98 | 8427 | 23 | AB | 2 | KH | 158.9 |
| 98 | 8427 | 24 | AB | 2 | PAB | 176.8 |
| 98 | 8428 | 27 | AB | 2 | KH | 1224 |
| 98 | 8428 | 28 | AB | 2 | KH | 15.4 |
| 99 | 8492 | 38 | AB | 2 | KH | 148.3 |
| 99 | 8492 | 39 | AB | 2 | KH | 161.9 |
| 99 | 8492 | 233 | AB | 2 | KH | 11.4 |
| 99 | 8492 | 234 | AB | 2 | KH | 284.8 |
| 99 | 8492 | 235 | AB | 2 | KH | 25.8 |
| 99 | 8492 | 246 | AB | 2 | KH | 158.3 |
| 99 | 8492 | 247 | AB | 2 | KH | 22.2 |
| 99 | 8492 | 248 | AB | 2 | KH | 72.1 |
| 99 | 8492 | 249 | AB | 2 | KH | 82.7 |
| 99 | 8492 | 250 | AB | 2 | KH | 90.3 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 98 | 8432 | 50 | AB | 2 | KH | 138.7 |
| 98 | 8433 | 11 | AB | 2 | PAB | 318.5 |
| 98 | 8433 | 40 | AB | 2 | UNK | 23.4 |
| 98 | 8436 | 11 | AB | 2 | KH | 64.5 |
| 98 | 8436 | 12 | AB | 2 | KH | 65.4 |
| 98 | 8436 | 13 | AB | 2 | KH | 68.7 |
| 98 | 8436 | 14 | AB | 2 | KH | 79.8 |
| 98 | 8436 | 27 | AB | 2 | KH | 2500 |
| 98 | 8436 | 29 | AB | 2 | KH | 18.2 |
| 98 | 8437 | 16 | AB | 2 | PAB | 51.8 |
| 98 | 8439 | 26 | AB | S&D | KH | 103.1 |
| 98 | 8439 | 27 | AB | S&D | UNK | 46.3 |
| 98 | 8439 | 70 | AB | S&D | UNK | 10.4 |
| 98 | 8440 | 80 | AB | S&D | KH | 34.5 |
| 98 | 8440 | 3 | AB | S&D | UNK | 100.3 |
| 98 | 8440 | 79 | AB | S&D | UNK | 218.5 |
| 98 | 8452 | 6 | AB | 2 | KH | 67.3 |
| 98 | 8461 | 7 | AB | 2 | UNK | 33.5 |
| 98 | 8463 | 1 | AB | 2 | KH | 154.7 |
| 98 | 8480 | 11 | AB | 1 | KH | 34.8 |
| 98 | 8482 | 8 | AB | 1 | KH | 132.4 |
| 98 | 8486 | 30 | AB | 2 | KH | 364.4 |
| 98 | 8486 | 31 | AB | 2 | KH | 187.5 |
| 98 | 8486 | 3 | AB | 2 | UNK | 170.5 |
| 98 | 8486 | 29 | AB | 2 | UNK | 66.8 |
| 98 | 8487 | 37 | AB | 2 | KH | 27 |
| 98 | 8487 | 38 | AB | 2 | KH | 216.5 |
| 98 | 8490 | 102 | AB | 2 | DQ | 22 |
| 99 | 8490 | 99 | AB | 2 | KH | 17 |
| 99 | 8490 | 100 | AB | 2 | KH | 65 |
| 99 | 8490 | 101 | AB | 2 | KH | 24 |
| 99 | 8490 | 121 | AB | 2 | KH | 114 |
| 99 | 8492 | 35 | AB | 2 | KH | 290 |
| 99 | 8492 | 36 | AB | 2 | KH | 136.3 |
| 99 | 8492 | 37 | AB | 2 | KH | 129.1 |
| 98 | 8551 | 1 | AB | 1 | KH | 86.2 |
| 98 | 8554 | 3 | AB | 1 | GSS | 28.3 |
| 98 | 8562 | 28 | AB | 1 | UNK | 269.9 |
| 98 | 8576 | 1 | AB | 1 | KH | 176.2 |
| 98 | 8582 | 17 | AB | 1 | KH | 89.4 |
| 98 | 8588 | 10 | AB | 1 | KH | 3.8 |
| 98 | 8588 | 11 | AB | 1 | KH | 18.8 |
| 98 | 8590 | 3 | AB | 1 | KH | 520.5 |
| 98 | 8600 | 10 | F | S&D | GSS | 970 |
| 98 | 8600 | 9 | F | S&D | PAB | 520 |
| 98 | 8600 | 31 | F | S&D | PAB | 240 |
| 98 | 8601 | 10 | F | S&D | DQ | 142 |
| 98 | 8601 | 9 | F | S&D | UNK | 71 |
| 98 | 8602 | 8 | F | S&D | DQ | 300 |
| 98 | 8602 | 7 | F | S&D | UNK | 152.9 |
| 98 | 8603 | 46 | F | S&D | DQ | 42.4 |
| 98 | 8603 | 47 | F | S&D | PAB | 292.7 |
| 98 | 8603 | 48 | F | S&D | PAB | 133.3 |
| 98 | 8603 | 5 | F | S&D | UNK | 115 |
| 98 | 8604 | 21 | F | S&D | PAB | 1101 |
| 98 | 8607 | 1 | F | S&D | DQ | 6000 |
| 98 | 8607 | 56 | F | S&D | DQ | 639.9 |
| 98 | 8607 | 55 | F | S&D | UNK | 29.3 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 99 | 8492 | 251 | AB | 2 | KH | 115 |
| 99 | 8492 | 252 | AB | 2 | KH | 139.8 |
| 99 | 8492 | 253 | AB | 2 | KH | 66.8 |
| 99 | 8492 | 15 | AB | 2 | UNK | 146.8 |
| 99 | 8493 | 13 | AB | 2 | KH | 130.1 |
| 98 | 8499 | 174 | AB | 2 | UNK | 2103 |
| 98 | 8499 | 295 | AB | 2 | UNK | 1332 |
| 98 | 8501 | 6 | AB | 1 | UNK | 20.3 |
| 98 | 8502 | 7 | AB | 1 | PAB | 19.2 |
| 98 | 8503 | 8 | AB | 1 | KH | 7.7 |
| 98 | 8503 | 9 | AB | 1 | KH | 149.8 |
| 98 | 8509 | 9 | AB | 1 | KH | 7.1 |
| 98 | 8509 | 9 | AB | 1 | KH | 18.4 |
| 98 | 8511 | 31 | AB | 1 | KH | 25.7 |
| 98 | 8515 | 9 | AB | 1 | GSS | 76 |
| 98 | 8517 | 3 | AB | 1 | KH | 18.1 |
| 98 | 8517 | 4 | AB | 1 | KH | 31.4 |
| 98 | 8518 | 8 | AB | 1 | KH | 172.1 |
| 98 | 8518 | 9 | AB | 1 | KH | 80.5 |
| 98 | 8518 | 10 | AB | 1 | KH | 63.6 |
| 98 | 8518 | 17 | AB | 1 | KH | 65.3 |
| 98 | 8518 | 18 | AB | 1 | KH | 49.5 |
| 98 | 8518 | 19 | AB | 1 | KH | 38 |
| 98 | 8518 | 20 | AB | 1 | KH | 34.5 |
| 98 | 8518 | 21 | AB | 1 | KH | 23.5 |
| 98 | 8518 | 22 | AB | 1 | KH | 20.2 |
| 98 | 8518 | 23 | AB | 1 | KH | 12.5 |
| 98 | 8525 | 5 | AB | 1 | KH | 6.3 |
| 98 | 8528 | 4 | AB | 1 | KH | 43.3 |
| 98 | 8530 | 11 | AB | 1 | UNK | 137.4 |
| 98 | 8531 | 1 | AB | 1 | KH | 120 |
| 98 | 8531 | 2 | AB | 1 | UNK | 105.5 |
| 98 | 8532 | 2 | AB | 1 | KH | 95 |
| 98 | 8533 | 7 | AB | 1 | DQ | 80.2 |
| 98 | 8544 | 8 | AB | 1 | KH | 1491 |
| 98 | 8663 | 22 | F | 3C | DQ | 184.5 |
| 98 | 8667 | 41 | F | 3C | DQ | 558 |
| 98 | 8667 | 42 | F | 3C | DQ | 122.5 |
| 98 | 8668 | 26 | F | 3C | UNK | 41.5 |
| 98 | 8669 | 13 | F | S&D | PAB | 102.3 |
| 98 | 8673 | 15 | F | S&D | UNK | 167.3 |
| 98 | 8679 | 7 | F | 3C | PAB | 529.3 |
| 98 | 8684 | 7 | F | 3C | UNK | 116.4 |
| 98 | 8707 | 2 | F | 3C | UNK | 3.3 |
| 98 | 8717 | 4 | F | 3C | PAB | 7.8 |
| 98 | 8727 | 3 | F | 3C | DQ | 180.6 |
| 98 | 8727 | 5 | F | 3C | GSS | 244.2 |
| 98 | 8727 | 4 | F | 3C | UNK | 184.8 |
| 98 | 8727 | 7 | F | 3C | UNK | 1570 |
| 2000 | 8750 | 8 | F | S&D | UNK | 125 |
| 2000 | 8753 | 16 | F | S&D | DQ | 185.7 |
| 99 | 8754 | 34 | F | 3C | DQ | 208.1 |
| 99 | 8754 | 35 | F | 3C | DQ | 98.7 |
| 99 | 8754 | 33 | F | 3C | KH | 258.9 |
| 99 | 8754 | 2 | F | 3C | PAB | 800.5 |
| 99 | 8754 | 36 | F | 3C | UNK | 264.5 |
| 99 | 8754 | 37 | F | 3C | UNK | 7.4 |
| 99 | 8755 | 74 | F | 3C | DQ | 50.6 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 98 | 8609 | 9 | F | 3C | UNK | 991.5 |
| 98 | 8616 | 24 | F | S&D | UNK | 346 |
| 98 | 8617 | 1 | F | 3C | DQ | 55.7 |
| 98 | 8619 | 5 | F | 3C | DQ | 20.6 |
| 98 | 8625 | 10 | F | 3C | DQ | 90.5 |
| 98 | 8625 | 9 | F | 3C | UNK | 282 |
| 98 | 8630 | 55 | F | 3C | UNK | 50 |
| 98 | 8636 | 1 | F | 3C | DQ | 57 |
| 98 | 8639 | 3 | F | 3C | UNK | 321.5 |
| 98 | 8641 | 8 | F | 3C | DQ | 58.3 |
| 98 | 8641 | 7 | F | 3C | GSS | 598.4 |
| 98 | 8641 | 9 | F | 3C | PAB | 807.7 |
| 98 | 8642 | 2 | F | 3C | GSS | 2266 |
| 98 | 8642 | 4 | F | 3C | KH | 204 |
| 98 | 8642 | 5 | F | 3C | UNK | 607 |
| 98 | 8645 | 3 | F | 3C | UNK | 56.3 |
| 98 | 8649 | 15 | F | 3C | DQ | 58.8 |
| 98 | 8652 | 2 | F | 3C | PAB | 27.5 |
| 98 | 8654 | 24 | F | 3C | PAB | 123 |
| 98 | 8660 | 3 | F | 3C | UNK | 38.5 |
| 98 | 8662 | 2 | F | 3C | UNK | 115.3 |
| 98 | 8662 | 8 | F | 3C | UNK | 72.5 |
| 99 | 8757 | 214 | F | 3C | UNK | 92.9 |
| 99 | 8758 | 4 | F | 3C | UNK | 40 |
| 99 | 8758 | 5 | F | 3C | UNK | 87.8 |
| 99 | 8758 | 6 | F | 3C | UNK | 87.6 |
| 99 | 8758 | 7 | F | 3C | UNK | 39.8 |
| 99 | 8760 | 155 | F | 3C | KH | 34.3 |
| 99 | 8760 | 39 | F | 3C | UNK | 24.7 |
| 99 | 8760 | 42 | F | 3C | UNK | 83.7 |
| 99 | 8760 | 43 | F | 3C | UNK | 31.9 |
| 99 | 8760 | 44 | F | 3C | UNK | 68.4 |
| 99 | 8763 | 77 | F | 3C | PAB | 157 |
| 99 | 8763 | 40 | F | 3C | UNK | 43.7 |
| 99 | 8763 | 41 | F | 3C | UNK | 57.5 |
| 99 | 8763 | 74 | F | 3C | UNK | 7.2 |
| 99 | 8763 | 78 | F | 3C | UNK | 335 |
| 99 | 8764 | 122 | F | S&D | DQ | 598 |
| 99 | 8764 | 144 | F | S&D | DQ | 13.7 |
| 99 | 8764 | 173 | F | S&D | DQ | 7.2 |
| 99 | 8764 | 136 | F | S&D | PAB | 1.7 |
| 99 | 8764 | 140 | F | S&D | UNK | 137.6 |
| 99 | 8764 | 142 | F | S&D | UNK | 3.7 |
| 99 | 8764 | 145 | F | S&D | UNK | 36.8 |
| 99 | 8764 | 171 | F | S&D | UNK | 4.6 |
| 99 | 8764 | 174 | F | S&D | UNK | 44.5 |
| 99 | 8764 | 245 | F | S&D | UNK | 57.8 |
| 99 | 8764 | 266 | F | S&D | UNK | 8.8 |
| 99 | 8774 | 70 | F | 3C | DQ | 177.1 |
| 99 | 8774 | 12 | F | 3C | GSS | 199 |
| 99 | 8774 | 86 | F | 3C | KH | 16 |
| 99 | 8774 | 67 | F | 3C | UNK | 2.1 |
| 99 | 8774 | 87 | F | 3C | UNK | 78 |
| 99 | 8775 | 32 | F | 3C | GSS | 33.9 |
| 99 | 8775 | 33 | F | 3C | UNK | 21 |
| 99 | 8776 | 62 | F | 3C | DQ | 382.5 |
| 99 | 8776 | 121 | F | 3C | KH | 128.2 |
| 99 | 8776 | 63 | F | 3C | PAB | 963.9 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 99 | 8755 | 82 | F | 3C | DQ | 257.5 |
| 99 | 8755 | 77 | F | 3C | GSS | 813.5 |
| 99 | 8755 | 81 | F | 3C | GSS | 346.5 |
| 99 | 8755 | 79 | F | 3C | KH | 304.5 |
| 99 | 8755 | 75 | F | 3C | PAB | 44.2 |
| 99 | 8755 | 78 | F | 3C | PAB | 350.8 |
| 99 | 8755 | 83 | F | 3C | UNK | 31.1 |
| 99 | 8756 | 69 | F | 3C | GSS | 545.5 |
| 99 | 8756 | 87 | F | 3C | GSS | 131.8 |
| 99 | 8756 | 43 | F | 3C | PAB | 133.9 |
| 99 | 8756 | 45 | F | 3C | PAB | 249.4 |
| 99 | 8756 | 46 | F | 3C | PAB | 711 |
| 99 | 8756 | 80 | F | 3C | PAB | 641.3 |
| 99 | 8756 | 84 | F | 3C | PAB | 227.8 |
| 99 | 8756 | 40 | F | 3C | UNK | 178 |
| 99 | 8756 | 42 | F | 3C | UNK | 95.9 |
| 99 | 8756 | 44 | F | 3C | UNK | 193.1 |
| 99 | 8757 | 78 | F | 3C | DQ | 446.5 |
| 99 | 8757 | 79 | F | 3C | DQ | 83.7 |
| 99 | 8757 | 80 | F | 3C | DQ | 280.5 |
| 99 | 8757 | 81 | F | 3C | UNK | 169.3 |
| 99 | 8757 | 82 | F | 3C | UNK | 51.9 |
| 99 | 8777 | 40 | F | 3C | UNK | 43.7 |
| 99 | 8777 | 41 | F | 3C | UNK | 12.1 |
| 99 | 8777 | 42 | F | 3C | UNK | 13.8 |
| 99 | 8778 | 50 | F | 3C | UNK | 84.3 |
| 99 | 8778 | 51 | F | 3C | UNK | 28.9 |
| 99 | 8779 | 24 | F | 3C | DQ | 165 |
| 99 | 8780 | 46 | F | 3C | DQ | 631.7 |
| 99 | 8780 | 66 | F | 3C | DQ | 6.3 |
| 99 | 8780 | 47 | F | 3C | UNK | 56.7 |
| 99 | 8780 | 73 | F | 3C | UNK | 20.5 |
| 99 | 8788 | 28 | F | 3C | PAB | 470.8 |
| 99 | 8795 | 20 | F | 3C | DQ | 231.7 |
| 99 | 8795 | 21 | F | 3C | UNK | 121.9 |
| 99 | 8796 | 23 | F | 3C | DQ | 3.5 |
| 99 | 8796 | 31 | F | 3C | DQ | 254.7 |
| 99 | 8796 | 30 | F | 3C | UNK | 712 |
| 99 | 8806 | 28 | E | S&D | UNK | 18.6 |
| 99 | 8821 | 32 | E | 3C | DQ | 384.4 |
| 99 | 8821 | 33 | E | 3C | DQ | 570.9 |
| 99 | 8821 | 23 | E | 3C | GSS | 980.6 |
| 99 | 8827 | 18 | E | 3C | KH | 978.8 |
| 99 | 8828 | 7 | E | S&D | PAB | 70.5 |
| 99 | 8829 | 31 | E | S&D | DQ | 39.4 |
| 99 | 8830 | 2 | E | S&D | PAB | 390.1 |
| 99 | 8830 | 3 | E | S&D | PAB | 80.9 |
| 99 | 8831 | 4 | E | S&D | DQ | 49.6 |
| 99 | 8831 | 5 | E | S&D | PAB | 1059 |
| 99 | 8832 | 1 | E | 3C | DQ | 584.3 |
| 99 | 8834 | 9 | E | 3C | DQ | 1490 |
| 99 | 8840 | 1 | E | S&D | PAB | 375.7 |
| 99 | 8843 | 7 | E | S&D | PAB | 149.6 |
| 99 | 8844 | 9 | E | S&D | DQ | 43.2 |
| 99 | 8845 | 12 | E | S&D | UNK | 31.8 |
| 99 | 8846 | 3 | E | S&D | UNK | 107.1 |
| 99 | 8857 | 6 | E | 3C | DQ | 9.1 |
| 99 | 8858 | 34 | E | 3C | UNK | 21.5 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 99 | 8776 | 120 | F | 3C | PAB | 844 |
| 99 | 8776 | 46 | F | 3C | UNK | 246.3 |
| 99 | 8776 | 117 | F | 3C | UNK | 5500 |
| 99 | 8777 | 39 | F | 3C | GSS | 17.9 |
| 99 | 8777 | 26 | F | 3C | UNK | 8.7 |
| 99 | 8777 | 27 | F | 3C | UNK | 150.6 |
| 99 | 8777 | 28 | F | 3C | UNK | 149.8 |
| 99 | 8777 | 37 | F | 3C | UNK | 44.5 |
| 99 | 8777 | 38 | F | 3C | UNK | 5.4 |
| 99 | 8860 | 13 | E | 3C | PAB | 174.3 |
| 99 | 8864 | 72 | E | S&D | DQ | 979 |
| 99 | 8864 | 69 | E | S&D | UNK | 99.3 |
| 99 | 8864 | 70 | E | S&D | UNK | 51.5 |
| 99 | 8864 | 71 | E | S&D | UNK | 82.3 |
| 99 | 8866 | 9 | E | 3C | PAB | 237.5 |
| 99 | 8867 | 39 | E | 3C | DQ | 130.7 |
| 99 | 8871 | 4 | E | 3C | DQ | 137.1 |
| 99 | 8884 | 2 | E | S&D | DQ | 490.4 |
| 99 | 8884 | 3 | E | S&D | UNK | 378 |
| 99 | 8887 | 13 | E | S&D | DQ | 22.2 |
| 99 | 8889 | 16 | E | 3C | PAB | 733 |
| 99 | 8890 | 31 | E | 3C | DQ | 35.7 |
| 99 | 8890 | 82 | E | 3C | KH | 378 |
| 99 | 8890 | 74 | E | 3C | PAB | 923 |
| 99 | 8890 | 80 | E | 3C | PAB | 391 |
| 99 | 8890 | 99 | E | 3C | PAB | 454 |
| 99 | 8890 | 32 | E | 3C | UNK | 66.8 |
| 99 | 8890 | 33 | E | 3C | UNK | 81.1 |
| 99 | 8894 | 20 | E | S&D | DQ | 583 |
| 99 | 8896 | 20 | E | 3C | UNK | 26.6 |
| 99 | 8898 | 1 | E | 3C | UNK | 110.1 |
| 99 | 8907 | 1 | AB | 1 | UNK | 205 |
| 99 | 8936 | 15 | AB | 2 | KH | 53.5 |
| 99 | 8938 | 54 | AB | S&D | KH | 42.1 |
| 99 | 8938 | 55 | AB | S&D | KH | 170.1 |
| 99 | 8939 | 229 | AB | S&D | DQ | 665.8 |
| 99 | 8939 | 230 | AB | S&D | DQ | 178.7 |
| 99 | 8939 | 232 | AB | S&D | DQ | 130.2 |
| 99 | 8939 | 236 | AB | S&D | DQ | 66.4 |
| 99 | 8939 | 237 | AB | S&D | DQ | 28.1 |
| 99 | 8939 | 243 | AB | S&D | DQ | 592.5 |
| 99 | 8939 | 231 | AB | S&D | PAB | 109.9 |
| 99 | 8939 | 244 | AB | S&D | PAB | 309.5 |
| 99 | 8939 | 245 | AB | S&D | PAB | 323.5 |
| 99 | 8939 | 246 | AB | S&D | PAB | 351 |
| 99 | 8939 | 238 | AB | S&D | UNK | 43.7 |
| 99 | 8939 | 241 | AB | S&D | UNK | 87.1 |
| 99 | 8939 | 242 | AB | S&D | UNK | 65.8 |
| 99 | 8939 | 247 | AB | S&D | UNK | 155 |
| 99 | 8939 | 248 | AB | S&D | UNK | 43.5 |
| 99 | 8939 | 249 | AB | S&D | UNK | 9.2 |
| 99 | 8939 | 250 | AB | S&D | UNK | 3.2 |
| 99 | 8939 | 258 | AB | S&D | UNK | 31 |
| 99 | 8940 | 12 | AB | S&D | KH | 220 |
| 2001 | 9059 | 5 | E | 3C | UNK | 351 |
| 2001 | 9059 | 7 | E | 3C | UNK | 533 |
| 2001 | 9065 | 7 | E | 3C | UNK | 25 |
| 2001 | 9067 | 39 | E | S&D | PAB | 107 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 99 | 8858 | 38 | E | 3C | UNK | 294 |
| 99 | 8859 | 51 | E | 3C | DQ | 267 |
| 99 | 8859 | 46 | E | 3C | KH | 32.1 |
| 99 | 8859 | 8 | E | 3C | PAB | 343.3 |
| 99 | 8859 | 47 | E | 3C | PAB | 370 |
| 99 | 8859 | 49 | E | 3C | PAB | 133.3 |
| 99 | 8859 | 45 | E | 3C | SR | 116 |
| 99 | 8859 | 48 | E | 3C | UNK | 29.4 |
| 99 | 8860 | 14 | E | 3C | GSS | 227.2 |
| 99 | 8940 | 5 | AB | S&D | UNK | 765.3 |
| 99 | 8940 | 9 | AB | S&D | UNK | 778 |
| 99 | 8940 | 10 | AB | S&D | UNK | 863.8 |
| 99 | 8940 | 11 | AB | S&D | UNK | 286.9 |
| 99 | 8940 | 33 | AB | S&D | UNK | 10.5 |
| 99 | 8941 | 61 | AB | 2 | PAB | 225.5 |
| 99 | 8941 | 63 | AB | 2 | UNK | 297.7 |
| 99 | 8943 | 61 | AB | 2 | KH | 72.3 |
| 99 | 8944 | 81 | AB | 2 | KH | 90.5 |
| 99 | 8944 | 82 | AB | 2 | KH | 26 |
| 99 | 8944 | 85 | AB | 2 | KH | 45.3 |
| 99 | 8950 | 24 | AB | 2 | PAB | 192.1 |
| 99 | 8954 | 11 | AB | 2 | UNK | 78.5 |
| 99 | 8960 | 11 | AB | 2 | KH | 70.7 |
| 99 | 8960 | 12 | AB | 2 | KH | 105.8 |
| 99 | 8961 | 18 | AB | 2 | KH | 177.8 |
| 99 | 8963 | 1 | AB | 2 | KH | 155 |
| 99 | 8963 | 13 | AB | 2 | KH | 326.5 |
| 99 | 8963 | 14 | AB | 2 | KH | 260 |
| 2000 | 8983 | 53 | AB | 2 | KH | 100.2 |
| 2000 | 8983 | 54 | AB | 2 | KH | 55.9 |
| 2000 | 8984 | 81 | AB | 2 | KH | 726 |
| 2000 | 8990 | 117 | AB | 2 | GSS | 141.2 |
| 2000 | 8990 | 84 | AB | 2 | UNK | 16.1 |
| 2000 | 8990 | 118 | AB | 2 | UNK | 118 |
| 2000 | 8990 | 120 | AB | 2 | UNK | 44.4 |
| 2000 | 8996 | 27 | AB | 2 | KH | 1171 |
| 2001 | 9004 | 12 | E | S&D | DQ | 64.5 |
| 2001 | 9004 | 18 | E | S&D | DQ | 231 |
| 2001 | 9004 | 16 | E | S&D | PAB | 558 |
| 2001 | 9004 | 8 | E | S&D | UNK | 130.8 |
| 2001 | 9006 | 1 | E | S&D | DQ | 290.6 |
| 2001 | 9007 | 20 | E | S&D | UNK | 146.1 |
| 2001 | 9010 | 21 | E | 3C | UNK | 512.3 |
| 2001 | 9017 | 3 | E | 3C | PAB | 95.5 |
| 2001 | 9043 | 3 | E | 3C | DQ | 43 |
| 2001 | 9044 | 13 | E | 3C | PAB | 513 |
| 2001 | 9051 | 6 | E | 3C | PAB | 663.5 |
| 2001 | 9051 | 14 | E | 3C | PAB | 43.8 |
| 2001 | 9051 | 23 | E | 3C | PAB | 54.3 |
| 2001 | 9056 | 20 | E | 3C | UNK | 104.7 |
| 2001 | 9057 | 14 | E | 3C | PAB | 234 |
| 2001 | 9059 | 6 | E | 3C | PAB | 51.3 |
| 2001 | 9059 | 75 | E | 3C | PAB | 277 |
| 2001 | 9059 | 76 | E | 3C | PAB | 234 |
| 99 | 9401 | 38 | AB | S&D | UNK | 38.5 |
| 99 | 9401 | 39 | AB | S&D | UNK | 3.4 |
| 99 | 9406 | 1 | AB | 3B | DQ | 991.6 |
| 99 | 9406 | 2 | AB | 3B | DQ | 660.7 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 2001 | 9069 | 2 | E | 3C | PAB | 113.8 |
| 2001 | 9076 | 4 | E | 3C | DQ | 304 |
| 2001 | 9076 | 2 | E | 3C | UNK | 251.9 |
| 2001 | 9079 | 24 | E | 3C | GSS | 303 |
| 2001 | 9079 | 21 | E | 3C | PAB | 1071 |
| 2001 | 9079 | 20 | E | 3C | UNK | 1148 |
| 2001 | 9091 | 7 | E | 3C | PAB | 342 |
| 2001 | 9091 | 8 | E | 3C | PAB | 1462 |
| 2001 | 9091 | 10 | E | 3C | UNK | 1202 |
| 2001 | 9091 | 54 | E | 3C | UNK | 140 |
| 2001 | 9092 | 2 | E | 3C | GSS | 3000 |
| 2001 | 9097 | 1 | E | 3C | PAB | 1394 |
| 99 | 9103 | 2 | F | 3C | UNK | 15.7 |
| 99 | 9108 | 39 | F | 3C | PAB | 340.7 |
| 99 | 9110 | 39 | F | 3C | DQ | 88.8 |
| 99 | 9110 | 40 | F | 3C | DQ | 41 |
| 99 | 9110 | 41 | F | 3C | DQ | 27.9 |
| 99 | 9110 | 21 | F | 3C | UNK | 24.7 |
| 99 | 9112 | 15 | F | 3C | DQ | 271.8 |
| 99 | 9113 | 43 | F | 3C | DQ | 248.2 |
| 99 | 9113 | 44 | F | 3C | DQ | 234.1 |
| 99 | 9115 | 30 | F | 3C | DQ | 3.6 |
| 99 | 9120 | 20 | F | 3C | DQ | 218.8 |
| 99 | 9120 | 19 | F | 3C | GSS | 165.1 |
| 99 | 9120 | 18 | F | 3C | UNK | 4.5 |
| 99 | 9129 | 2 | F | 3C | DQ | 11 |
| 99 | 9131 | 1 | F | 3C | UNK | 123 |
| 99 | 9203 | 1 | F | S&D | DQ | 188.1 |
| 99 | 9203 | 2 | F | S&D | DQ | 133 |
| 99 | 9203 | 3 | F | S&D | DQ | 126 |
| 99 | 9205 | 16 | F | 3C | DQ | 261 |
| 99 | 9205 | 17 | F | 3C | UNK | 158.7 |
| 99 | 9210 | 20 | F | S&D | PAB | 8.8 |
| 99 | 9211 | 17/18 | F | S&D | PAB | 63.5 |
| 99 | 9237 | 1 | F | 3C | PAB | 724.8 |
| 99 | 9241 | 1 | F | 3C | UNK | 291.6 |
| 99 | 9400 | 12 | AB | S&D | UNK | 8.3 |
| 99 | 9400 | 14 | AB | S&D | UNK | 622.3 |
| 99 | 9401 | 33 | AB | S&D | UNK | 12.5 |
| 99 | 9401 | 34 | AB | S&D | UNK | 10 |
| 99 | 9401 | 37 | AB | S&D | UNK | 29 |
| 99 | 9604 | 45 | E | S&D | PAB | 201.8 |
| 99 | 9604 | 46 | E | S&D | PAB | 425.5 |
| 99 | 9606 | 46 | E | S&D | DQ | 142.7 |
| 99 | 9606 | 47 | E | S&D | DQ | 744 |
| 99 | 9606 | 49 | E | S&D | DQ | 177.2 |
| 99 | 9606 | 48 | E | S&D | PAB | 177.7 |
| 99 | 9606 | 50 | E | S&D | PAB | 106.1 |
| 2001 | 9611 | 67 | E | 3C | DQ | 94 |
| 2001 | 9611 | 66 | E | 3C | GSS | 28.6 |
| 2001 | 9611 | 68 | E | 3C | UNK | 17.6 |
| 2001 | 9612 | 103 | E | 3C | DQ | 127.3 |
| 2001 | 9612 | 108 | E | 3C | DQ | 303 |
| 2001 | 9612 | 104 | E | 3C | GSS | 117.4 |
| 2001 | 9612 | 106 | E | 3C | GSS | 198.5 |
| 2001 | 9612 | 107 | E | 3C | PAB | 623.7 |
| 2001 | 9613 | 5 | E | 3C | PAB | 249.3 |
| 2001 | 9613 | 6 | E | 3C | PAB | 80.9 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 99 | 9408 | 38 | AB | 3B | UNK | 375.4 |
| 99 | 9409 | 8 | AB | 3B | KH | 398.5 |
| 99 | 9413 | 124 | AB | S&D | KH | 151.7 |
| 99 | 9413 | 74 | AB | S&D | UNK | 44.5 |
| 99 | 9413 | 75 | AB | S&D | UNK | 46 |
| 99 | 9413 | 76 | AB | S&D | UNK | 22.7 |
| 99 | 9413 | 77 | AB | S&D | UNK | 24.9 |
| 99 | 9413 | 78 | AB | S&D | UNK | 232.9 |
| 99 | 9413 | 121 | AB | S&D | UNK | 35.5 |
| 99 | 9413 | 122 | AB | S&D | UNK | 18 |
| 99 | 9413 | 123 | AB | S&D | UNK | 44.3 |
| 99 | 9421 | 1 | AB | 3B | KH | 29.3 |
| 99 | 9432 | 23 | AB | S&D | UNK | 30.8 |
| 99 | 9432 | 35 | AB | S&D | UNK | 645.2 |
| 99 | 9435 | 7 | AB | 3B | UNK | 35.5 |
| 2000 | 9438 | 26 | AB | S&D | KH | 35 |
| 2000 | 9438 | 27 | AB | S&D | KH | 130.9 |
| 2000 | 9438 | 28 | AB | S&D | KH | 38.4 |
| 2000 | 9438 | 29 | AB | S&D | KH | 126.5 |
| 2000 | 9438 | 31 | AB | S&D | KH | 27.7 |
| 2000 | 9438 | 8 | AB | S&D | UNK | 28.2 |
| 2000 | 9438 | 32 | AB | S&D | UNK | 44 |
| 2000 | 9440 | 2 | AB | S&D | UNK | 91.1 |
| 2000 | 9444 | 3 | AB | 3B | KH | 46.6 |
| 2000 | 9504 | 40 | AB | 2 | KH | 94 |
| 2000 | 9507 | 39 | AB | 2 | UNK | 111.1 |
| 2000 | 9511 | 21 | AB | 2 | KH | 19.4 |
| 2000 | 9511 | 1 | AB | 2 | PAB | 72 |
| 2000 | 9514 | 14 | AB | 2 | KH | 84.5 |
| 2000 | 9514 | 96 | AB | 2 | UNK | 167.6 |
| 2000 | 9522 | 72 | AB | 3A | KH | 179.7 |
| 2000 | 9522 | 71 | AB | 3A | PAB | 563 |
| 2000 | 9555 | 11 | AB | 2 | DQ | 12 |
| 2000 | 9559 | 3 | AB | 2 | DQ | 49.4 |
| 2000 | 9586 | 14 | AB | 2 | KH | 34.8 |
| 2000 | 9588 | 37 | AB | 2 | GSS | 112.2 |
| 2000 | 9588 | 36 | AB | 2 | KH | 105.4 |
| 99 | 9600 | 8 | E | S&D | KH | 779.6 |
| 99 | 9600 | 1 | E | S&D | UNK | 3565 |
| 99 | 9600 | 9 | E | S&D | UNK | 1486 |
| 99 | 9604 | 44 | E | S&D | KH | 338 |
| 99 | 9722 | 11 | F | 3C | GSS | 418.5 |
| 99 | 9722 | 12 | F | 3C | GSS | 183.5 |
| 99 | 9722 | 31 | F | 3C | GSS | 238 |
| 99 | 9722 | 10 | F | 3C | KH | 396 |
| 99 | 9722 | 13 | F | 3C | UNK | 170.3 |
| 99 | 9724 | 49 | F | 3C | UNK | 120.4 |
| 99 | 9729 | 88 | F | 3C | UNK | 42.5 |
| 99 | 9729 | 92 | F | 3C | UNK | 67 |
| 99 | 9729 | 93 | F | 3C | UNK | 50 |
| 99 | 9742 | 5 | F | 3C | UNK | 9.4 |
| 99 | 9742 | 14 | F | 3C | UNK | 14.3 |
| 99 | 9743 | 11 | F | S&D | DQ | 802 |
| 99 | 9743 | 21 | F | S&D | GSS | 140 |
| 99 | 9743 | 12 | F | S&D | PAB | 216 |
| 99 | 9749 | 11 | F | 3C | DQ | 180 |
| 99 | 9752 | 4 | F | 3C | PAB | 423.7 |
| 99 | 9756 | 24 | F | 3C | DQ | 912.1 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 2001 | 9613 | 13 | E | 3C | PAB | 21.6 |
| 2001 | 9613 | 32 | E | 3C | PAB | 67.5 |
| 2001 | 9613 | 2 | E | 3C | UNK | 530.5 |
| 2001 | 9614 | 6 | E | 3C | DQ | 245.8 |
| 2001 | 9614 | 5 | E | 3C | PAB | 1238 |
| 2001 | 9615 | 80 | E | 3C | DQ | 113.1 |
| 2001 | 9615 | 1 | E | 3C | UNK | 329.9 |
| 99 | 9700 | 21 | F | S&D | UNK | 56.3 |
| 99 | 9700 | 22 | F | S&D | UNK | 34.5 |
| 99 | 9700 | 23 | F | S&D | UNK | 62.5 |
| 99 | 9700 | 24 | F | S&D | UNK | 93.8 |
| 99 | 9702 | 54 | F | 3C | DQ | 52.8 |
| 99 | 9702 | 70 | F | 3C | DQ | 192.7 |
| 99 | 9702 | 68 | F | 3C | PAB | 2.9 |
| 99 | 9702 | 69 | F | 3C | UNK | 3.7 |
| 99 | 9704 | 12 | F | S&D | KH | 229.7 |
| 99 | 9704 | 10 | F | S&D | UNK | 863.5 |
| 99 | 9704 | 11 | F | S&D | UNK | 300 |
| 99 | 9704 | 36 | F | S&D | UNK | 23.4 |
| 99 | 9714 | 9 | F | 3C | PAB | 285 |
| 99 | 9714 | 1 | F | 3C | UNK | 99.1 |
| 99 | 9714 | 3 | F | 3C | UNK | 202.4 |
| 99 | 9714 | 4 | F | 3C | UNK | 128.3 |
| 99 | 9715 | 3 | F | 3C | UNK | 169.6 |
| 99 | 9716 | 59 | F | S&D | KH | 44.5 |
| 99 | 9716 | 17 | F | S&D | UNK | 230.4 |
| 99 | 9718 | 24 | F | 3C | DQ | 292.1 |
| 99 | 9718 | 3 | F | 3C | UNK | 135.1 |
| 2000 | 9843 | 3 | F | 3C | PAB | 447 |
| 2000 | 9844 | 1 | F | 3C | UNK | 347 |
| 2000 | 9845 | 17 | F | 3C | DQ | 148.2 |
| 2000 | 9846 | 21 | F | 3C | UNK | 62.6 |
| 2000 | 9862 | 18 | F | 3C | UNK | 87.1 |
| 2000 | 9863 | 5 | F | 3C | UNK | 222.8 |
| 2000 | 9865 | 2 | F | 3C | UNK | 193.7 |
| 2000 | 9879 | 2 | F | 3C | UNK | 76 |
| 2000 | 9880 | 76 | F | 3C | DQ | 227.9 |
| 2000 | 9880 | 77 | F | 3C | DQ | 295 |
| 2000 | 9880 | 48 | F | 3C | UNK | 4.9 |
| 2000 | 9880 | 58 | F | 3C | UNK | 35.5 |
| 2000 | 9880 | 72 | F | 3C | UNK | 122.9 |
| 2000 | 9881 | 13 | F | 3C | UNK | 122.9 |
| 2000 | 9890 | 5 | F | 3C | DQ | 18.4 |
| 2003 | 9904 | 1 | AB | 3C | DQ | 203 |
| 2003 | 9904 | 23 | AB | 3C | DQ | 292.2 |
| 2003 | 9904 | 24 | AB | 3C | DQ | 579 |
| 2003 | 9904 | 26 | AB | 3C | DQ | 871 |
| 2003 | 9904 | 27 | AB | 3C | DQ | 1619 |
| 2003 | 9904 | 29 | AB | 3C | DQ | 449 |
| 2003 | 9904 | 44 | AB | 3C | DQ | 235.7 |
| 2003 | 9904 | 6 | AB | 3C | GSS | 965.6 |
| 2003 | 9904 | 34 | AB | 3C | GSS | 67.5 |
| 2003 | 9904 | 36 | AB | 3C | GSS | 536.8 |
| 2003 | 9904 | 3 | AB | 3C | PAB | 539.1 |
| 2003 | 9904 | 4 | AB | 3C | PAB | 538 |
| 2003 | 9904 | 5 | AB | 3C | PAB | 796.7 |
| 2003 | 9904 | 7 | AB | 3C | PAB | 350 |
| 2003 | 9904 | 14 | AB | 3C | PAB | 2500 |

| year | lot | record | location | context | material | grams |
|---|---|---|---|---|---|---|
| 99 | 9756 | 25 | F | 3C | DQ | 397 |
| 99 | 9756 | 26 | F | 3C | DQ | 210.8 |
| 99 | 9756 | 20 | F | 3C | GSS | 41.3 |
| 99 | 9756 | 27 | F | 3C | PAB | 35 |
| 99 | 9763 | 34 | F | 3C | UNK | 22 |
| 99 | 9773 | 13 | F | 3C | UNK | 111.3 |
| 99 | 9778 | 7 | F | 3C | UNK | 150 |
| 99 | 9779 | 19 | F | 3C | DQ | 22.4 |
| 99 | 9788 | 1 | F | 3C | UNK | 3.6 |
| 99 | 9788 | 5 | F | 3C | UNK | 291.8 |
| 2000 | 9807 | 12 | F | 3C | DQ | 35.2 |
| 2000 | 9810 | 78 | F | 3C | DQ | 281.7 |
| 2000 | 9810 | 41 | F | 3C | PAB | 353 |
| 2000 | 9812 | 1 | F | 3C | DQ | 27 |
| 2000 | 9812 | 2 | F | 3C | DQ | 26.1 |
| 2000 | 9812 | 4 | F | 3C | UNK | 76.4 |
| 2000 | 9818 | 12 | F | 3C | GSS | 354 |
| 2000 | 9818 | 14 | F | 3C | PAB | 18 |
| 2000 | 9818 | 15 | F | 3C | UNK | 155.9 |
| 2000 | 9822 | 8 | F | 3C | DQ | 16 |
| 2000 | 9822 | 9 | F | 3C | UNK | 85.1 |
| 2000 | 9829 | 18 | F | 3C | PAB | 300.3 |
| 2000 | 9839 | 16 | F | 3C | DQ | 36.5 |
| 2000 | 9840 | 12 | F | 3C | UNK | 45.8 |
| 2000 | 9841 | 7 | F | 3C | DQ | 201.8 |
| 2000 | 9841 | 1 | F | 3C | GSS | 1800 |
| 2000 | 9841 | 4 | F | 3C | UNK | 298 |
| 2000 | 9841 | 6 | F | 3C | UNK | 30.2 |
| 2003 | 9904 | 11 | AB | 3C | UNK | 264.9 |
| 2003 | 9904 | 22 | AB | 3C | UNK | 456 |
| 2003 | 9904 | 28 | AB | 3C | UNK | 1565 |
| 2003 | 9904 | 32 | AB | 3C | UNK | 2500 |
| 2003 | 9904 | 33 | AB | 3C | UNK | 364 |
| 2003 | 9904 | 35 | AB | 3C | UNK | 523 |
| 2003 | 9904 | 37 | AB | 3C | UNK | 385 |
| 2003 | 9904 | 40 | AB | 3C | UNK | 375 |
| 2003 | 9904 | 41 | AB | 3C | UNK | 791.9 |
| 2003 | 9904 | 43 | AB | 3C | UNK | 147.9 |
| 2004 | 9905 | 5 | AB | 3C | KH | 4000 |
| 2000 | 9919 | 1 | AB | 2 | UNK | 220.7 |
| 2000 | 9919 | 2 | AB | 2 | UNK | 366 |
| 2000 | 9924 | 1 | AB | 2 | DQ | 270.8 |
| 2000 | 9932 | 2 | AB | 2 | UNK | 88.3 |
| 2000 | 9964 | 26 | AB | 2 | KH | 92.8 |
| 2000 | 9964 | 3 | AB | 2 | PAB | 168.2 |
| 2000 | 9973 | 1 | AB | 2 | KH | 31.1 |
| 2000 | 9999 | 56 | n/a | n/a | PAB | 3500 |
| 2000 | 9999 | 160 | n/a | n/a | UNK | 567 |
| 2000 | 9999 | 165 | n/a | n/a | PAB | 290.8 |
| 2001 | 9999 | 166 | n/a | n/a | UNK | 86.5 |
| 2000 | 10000 | 1 | F | 3C | PAB | 31.2 |
| 2000 | 10011 | 1 | F | 3C | PAB | 392 |
| 2000 | 10025 | 5 | F | 3C | UNK | 69.9 |
| 2000 | 10030 | 1 | F | 3C | UNK | 31 |
| 2000 | 10031 | 6 | F | 3C | PAB | 377 |
| 2000 | 10036 | 3 | F | 3C | DQ | 182 |
| 2000 | 10044 | 21 | F | 3C | DQ | 124.1 |
| 2000 | 10047 | 5 | F | 3C | DQ | 230.8 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 2003 | 9904 | 17 | AB | 3C | PAB | 236 |
| 2003 | 9904 | 18 | AB | 3C | PAB | 507 |
| 2003 | 9904 | 19 | AB | 3C | PAB | 204 |
| 2003 | 9904 | 20 | AB | 3C | PAB | 678 |
| 2003 | 9904 | 21 | AB | 3C | PAB | 417.2 |
| 2003 | 9904 | 25 | AB | 3C | PAB | 1090 |
| 2003 | 9904 | 30 | AB | 3C | PAB | 572 |
| 2003 | 9904 | 31 | AB | 3C | PAB | 1054 |
| 2003 | 9904 | 38 | AB | 3C | PAB | 466.4 |
| 2003 | 9904 | 39 | AB | 3C | PAB | 279 |
| 2003 | 9904 | 42 | AB | 3C | PAB | 1158 |
| 2003 | 9904 | 2 | AB | 3C | UNK | 278.7 |
| 2003 | 9904 | 8 | AB | 3C | UNK | 690 |
| 2003 | 9904 | 9 | AB | 3C | UNK | 348 |
| 2003 | 9904 | 10 | AB | 3C | UNK | 1082 |
| 2001 | 11505 | 7 | E | S&D | UNK | 52.4 |
| 2001 | 11505 | 20 | E | S&D | UNK | 70.1 |
| 2001 | 11505 | 21 | E | S&D | UNK | 72.9 |
| 2001 | 11521 | 1 | E | 3C | DQ | 436 |
| 2001 | 11522 | 1 | E | 3C | PAB | 126.5 |
| 2001 | 11527 | 2 | E | 3C | UNK | 213.3 |
| 2001 | 11529 | 1 | E | 3C | DQ | 439.5 |
| 2001 | 11531 | 1 | E | 3C | PAB | 1037 |
| 2001 | 11534 | 12 | E | 3C | DQ | 256.7 |
| 2001 | 11535 | 1 | E | 3C | UNK | 544.8 |
| 2001 | 11542 | 18 | E | S&D | UNK | 193 |
| 2001 | 11549 | 17 | E | 3C | UNK | 52.3 |
| 2001 | 11559 | 48 | E | 3C | DQ | 491 |
| 2001 | 11560 | 17 | E | 3C | PAB | 95 |
| 2001 | 11568 | 1 | E | 3C | UNK | 141.3 |
| 2001 | 11577 | 1 | E | S&D | PAB | 52.1 |
| 2001 | 11581 | 10 | E | 3C | PAB | 240.2 |

| *year* | *lot* | *record* | *location* | *context* | *material* | *grams* |
|---|---|---|---|---|---|---|
| 2000 | 10047 | 4 | F | 3C | UNK | 166 |
| 2000 | 10048 | 2 | F | 3C | DQ | 2500 |
| 2000 | 10050 | 20 | F | 3C | DQ | 172 |
| 2000 | 10063 | 5 | F | 3C | DQ | 870 |
| 2000 | 10067 | 1 | F | 3C | DQ | 1322 |
| 2000 | 10067 | 2 | F | 3C | DQ | 1332 |
| 2000 | 11000 | 7 | AB | 2 | KH | 28.4 |
| 2000 | 11005 | 1 | AB | 2 | UNK | 55.7 |
| 2000 | 11060 | 16 | AB | 1 | KH | 1 |
| 2000 | 11060 | 17 | AB | 1 | KH | 1 |
| 2000 | 11060 | 15 | AB | 1 | UNK | 5.6 |
| 2000 | 11079 | 12 | AB | 2 | KH | 23.6 |
| 2000 | 11084 | 1 | AB | 1 | PAB | 236.8 |
| 2001 | 11500 | 1 | E | S&D | UNK | 17.3 |
| 2001 | 11504 | 2 | E | S&D | DQ | 856 |
| 2001 | 11701 | 26 | E | S&D | PAB | 2500 |
| 2001 | 11751 | 82 | E | S&D | DQ | 46 |
| 2001 | 11751 | 37 | E | S&D | PAB | 373.9 |
| 2001 | 11751 | 38 | E | S&D | PAB | 201.6 |
| 2001 | 11751 | 80 | E | S&D | PAB | 507 |
| 2001 | 11756 | 45 | E | 3C | UNK | 112 |
| 2001 | 11760 | 4 | E | 3C | PAB | 285 |
| 2001 | 11761 | 18 | E | 3C | DQ | 11.2 |
| 2001 | 11761 | 14 | E | 3C | PAB | 408.6 |
| 2001 | 11800 | 21 | E | S&D | UNK | 505 |
| 2001 | 11801 | 26 | E | S&D | DQ | 8 |
| 2001 | 11901 | 1 | E | 3C | PAB | 583 |
| 2001 | 11909 | 2 | E | 3C | PAB | 257.7 |
| 2001 | 11919 | 6 | E | 3C | UNK | 29.9 |
| 2001 | 11920 | 11 | E | 3C | PAB | 778.7 |
| 2001 | 11920 | 12 | E | 3C | UNK | 1780 |

# APPENDIX 5.2

# GRINDINGSTONES IN THE HARAPPA MUSEUM FROM PRE-1986 EXCAVATIONS

Most of the querns and mullers in the Harappa Museum Reserve Collection from pre-1986 exactions were marked with a Harappa Museum number (HM#). Many were also stenciled with an old excavation number. Those without any numbers were given a temporary one (T#).

| *Museum / temp #* | *stenciled #* | *material* | *grams* |
|---|---|---|---|
| HM#1524 | | UNK | 1500 |
| HM#65 | 980 | PAB | 5000 |
| HM#67 | | GSS | 20000 |
| HM#68 | 3498 | PAB | 1250 |
| HM#HPA93 | HPA222.92 | UNK | 1750 |
| HM#10410 | | UNK | 21000 |
| HM#10420 | | PAB | 4000 |
| HM#10438 | | UNK | 20500 |
| HM#10447 | | UNK | 2500 |
| HM#10452 | | UNK | 3500 |
| HM#10453 | | UNK | 14000 |
| HM#10455 | 980 | PAB | 5500 |
| HM#10456 | | DQ | 4500 |
| HM#10457 | | PAB | 1250 |
| HM#10458 | | GSS | 11000 |
| HM#10459 | | GSS | 11250 |
| HM#10460 | 319 | PAB | 4500 |
| HM#10461 | 37 | DQ | 15500 |
| HM#10462 | 8841 | GSS | 7250 |
| HM#10463 | | GSS | 3000 |
| HM#10464 | | PAB | 11500 |
| HM#10465 | 8327 | UNK | 14500 |
| HM#10466 | 334 | UNK | 9000 |
| HM#10467 | | DQ | 11000 |
| HM#10471 | | PAB | 6500 |
| HM#10472 | | UNK | 14000 |
| HM#10473 | | GSS | 6500 |
| HM#10474 | | GSS | 7500 |
| HM#10475 | 319 | PAB | 10000 |
| HM#10477 | | UNK | 14000 |
| HM#10479 | | UNK | 10250 |
| HM#10480 | 630 | UNK | 5500 |
| HM#10481 | 347 | UNK | 3500 |
| HM#10482 | | DQ | 3500 |
| HM#10483 | 3034 | UNK | 6000 |
| HM#10484 | 982 | PAB | 1750 |
| HM#10485 | | PAB | 2250 |
| HM#10530 | 2775 | DQ | 1250 |
| HM#10533 | 2400 | UNK | 1000 |
| HM#10536 | 54.395 | GSS | 4000 |
| HM#10537 | | UNK | 1000 |
| HM#10538 | | GSS | 2000 |
| HM#10546 | 318 | PAB | 10500 |
| HM#10547 | | PAB | 1500 |
| HM#10549 | | GSS | 2500 |
| HM#10550 | | UNK | 1250 |
| HM#10486 | | GSS | 7250 |
| HM#10487 | 3773 | PAB | 6500 |
| HM#10488 | 300 | DQ | 7000 |
| HM#10489 | 360 | PAB | 13250 |
| HM#10491 | | PAB | 10000 |
| HM#10492 | 3753 | DQ | 14000 |
| HM#10493 | | GSS | 8000 |
| HM#10494 | | PAB | 10000 |
| HM#10496 | | GSS | 11500 |
| HM#10497 | | UNK | 9500 |
| HM#10498 | | DQ | 9000 |
| HM#10500/1 | 8641 | PAB | 6500 |
| HM#10502 | | UNK | 4500 |
| HM#10504 | | PAB | 3500 |
| HM#10505 | | GSS | 1000 |
| HM#10506 | | DQ | 1000 |
| HM#10507 | | PAB | 1500 |
| HM#10508 | | UNK | 2000 |
| HM#10509 | 14031 | PAB | 3000 |
| HM#10510 | | PAB | 2500 |
| HM#10511 | | GSS | 2750 |
| HM#10512 | 1719 | PAB | 3500 |
| HM#10513 | | UNK | 2500 |
| HM#10515 | | PAB | 2000 |
| HM#10516 | | DQ | 1250 |
| HM#10517 | 36 | DQ | 3000 |
| HM#10518 | 9291 | GSS | 2500 |
| HM#10519 | | GSS | 2000 |
| HM#10520 | | GSS | 2250 |
| HM#10521 | 319 | PAB | 5000 |
| HM#10522 | | GSS | 2500 |
| HM#10523 | | UNK | 1500 |
| HM#10524 | | UNK | 1250 |
| HM#10525 | | UNK | 1500 |
| HM#10527 | | GSS | 3500 |
| HM#10528 | | UNK | 2250 |
| HM#10529 | 12842 | UNK | 1250 |
| HM#10532 | 12648 | GSS | 500 |
| T#44 | | GSS | 12500 |
| T#46 | | UNK | 10000 |
| T#48 | | GSS | 1500 |
| T#49 | | UNK | 2500 |
| T#50 | | UNK | 4000 |
| T#57 | 80798 | GSS | 9000 |
| T#58 | | GSS | 6750 |
| T#59 | | UNK | 7000 |

| *Museum / temp #* | *stenciled #* | *material* | *grams* |
|---|---|---|---|
| T#2 | 557R | UNK | 750 |
| T#3 | | UNK | 535 |
| T#4 | | GSS | 563 |
| T#5 | | GSS | 442 |
| T#6 | | UNK | 506 |
| T#7 | | UNK | 409 |
| T#8 | | PAB | 266 |
| T#9 | | PAB | 313 |
| T#10 | | GSS | 506 |
| T#11 | | GSS | 335 |
| T#12 | | GSS | 424 |
| T#13 | | UNK | 737 |
| T#14 | | UNK | 712 |
| T#15 | | UNK | 852 |
| T#16 | | UNK | 500 |
| T#18 | | PAB | 1110 |
| T#19 | | UNK | 1520 |
| T#20 | | UNK | 1250 |
| T#27 | PII43/9705 | UNK | 1500 |
| T#28 | | GSS | 1250 |
| T#29 | | UNK | 927 |
| T#30 | | UNK | 1750 |
| T#31 | | UNK | 1000 |
| T#32 | | GSS | 1500 |
| T#33 | | UNK | 6000 |
| T#34 | | UNK | 4000 |
| T#35 | | GSS | 2750 |
| T#36 | | GSS | 2500 |
| T#37 | | GSS | 4250 |
| T#38 | | GSS | 4500 |
| T#39 | | UNK | 4500 |
| T#40 | | UNK | 9000 |
| T#41 | | UNK | 9000 |
| T#42 | | UNK | 11500 |
| T#43 | | GSS | 3500 |

| *Museum / temp #* | *stenciled #* | *material* | *grams* |
|---|---|---|---|
| T#60 | | UNK | 22500 |
| T#61 | HPA92-93 | PAB | 7250 |
| T#62 | HPA_ET/24 | PAB | 18000 |
| T#63 | 982 | PAB | 4000 |
| T#64 | 1719 | UNK | 4750 |
| T#66 | | GSS | 8000 |
| T#69 | 318 | PAB | 11500 |
| T#70 | 980 | PAB | 3750 |
| T#71 | 3989 | PAB | 9750 |
| T#72 | | UNK | 10500 |
| T#73 | | UNK | 5000 |
| T#74 | | PAB | 1000 |
| T#75 | | DQ | 1500 |
| T#76 | | DQ | 1170 |
| T#77 | | UNK | 5250 |
| T#78 | | DQ | 4000 |
| T#79 | | DQ | 843 |
| T#80 | | GSS | 769 |
| T#81 | | UNK | 1300 |
| T#82 | | DQ | 1000 |
| T#83 | | GSS | 1250 |
| T#84 | | DQ | 1000 |
| T#85 | | UNK | 2250 |
| T#86 | | PAB | 2000 |
| T#87 | | DQ | 1750 |
| T#88 | 982 | PAB | 9000 |
| T#89 | | DQ | 3500 |
| T#90 | | DQ | 3500 |
| T#91 | | UNK | 5000 |
| T#92 | | PAB | 4500 |
| T#93 | | PAB | 13250 |
| T#94 | 319 | PAB | 7500 |
| T#95 | 3634 | DQ | 1000 |
| T#129 | | UNK | 5000 |
| T#131 | | UNK | 7000 |

# APPENDIX 6.1

## ELEMENTAL CONCENTRATIONS FOR 9 BLACK CHERT ARTIFACTS FROM HARAPPA

(parts per million)

| Figure 6.1 # | Artifact | Period | Trench | Al | Ce | Co | Cr | Eu | Fe | La | Mn | Na | Sc | Sm | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | H98/8546-5 | 1 | 39 | 3760 | 1.541 | 1.644 | 12.25 | 0.126 | 1542 | 0.984 | 31.52 | 1161 | 1.061 | 0.284 | 5.37 |
| 24 | H98/8489-25 | 2 | 39 | 2438 | 1.475 | 0.413 | 18.21 | 0.136 | 773 | 1.471 | 15.80 | 579 | 0.268 | 0.241 | 19.84 |
| 20 | H98/8554-18 | 1 | 39 | 3832 | 1.523 | 2.133 | 14.75 | 0.231 | 2615 | 0.977 | 29.43 | 1168 | 1.175 | 0.298 | 8.09 |
| 22 | H98/8558-4 | 1 | 39 | 4263 | 2.279 | 1.614 | 9.44 | 0.139 | 1981 | 1.440 | 25.34 | 1379 | 1.113 | 0.338 | 6.67 |
| 18 | H96/7517-1 | 1 | 39 | 3258 | 1.406 | 1.791 | 10.46 | 0.145 | 1928 | 0.851 | 25.79 | 920 | 0.928 | 0.268 | 5.57 |
| 19 | H96/7490-42 | 2 | 39 | 2345 | 0.732 | 0.501 | 15.67 | 0.125 | 1105 | 0.528 | 9.50 | 489 | 0.165 | 0.114 | 14.98 |
| 16 | H89/1062-9 | 2 | 52 | 2872 | 1.178 | 1.782 | 12.83 | 0.199 | 1634 | 0.732 | 34.09 | 786 | 0.965 | 0.223 | 6.20 |
| 17 | H2000/9598-4 | 2 | 39 | 2531 | 0.778 | 0.450 | 9.96 | 0.134 | 781 | 0.689 | 7.16 | 693 | 0.129 | 0.131 | 8.94 |
| 21 | H2001/2925-17 | S&D | 54 | 1826 | 2.904 | 0.425 | 4.73 | 0.144 | 575 | 1.100 | 5.24 | 199 | 0.174 | 0.369 | 7.21 |

# APPENDIX 6.2

## ELEMENTAL CONCENTRATIONS FOR BLACK CHERT SAMPLES FROM THE BOLAN PASS AND JAMMU

(parts per million)

| Location | Sample | Al | Ce | Co | Cr | Eu | Fe | La | Mn | Na | Sc | Sm | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dozan, Balochistan | BOLAN-1 | 2306 | 1.34 | 0.569 | 8.86 | 0.122 | 1166 | 1.664 | 35.98 | 259 | 0.297 | 0.31 | 6.66 |
| Dozan, Balochistan | BOLAN-2 | 2450 | 1.517 | 0.388 | 9.69 | 0.133 | 733 | 2.341 | 11.12 | 333 | 0.458 | 0.379 | 8.99 |
| Dozan, Balochistan | BOLAN-3 | 3022 | 1.782 | 2.941 | 4.87 | 0.141 | 2292 | 1.385 | 38.64 | 550 | 0.536 | 0.391 | 2.12 |
| Dozan, Balochistan | BOLAN-4 | 1887 | 1.14 | 0.457 | 8.53 | 0.122 | 1310 | 1.935 | 20.38 | 172 | 0.302 | 0.236 | 9.18 |
| Dozan, Balochistan | BOLAN-5 | 4059 | 3.435 | 1.956 | 9.23 | 0.202 | 2855 | 4.227 | 253.1 | 752 | 0.879 | 0.694 | 7.02 |
| Dozan, Balochistan | BOLAN-6 | 4216 | 3.519 | 0.974 | 9.88 | 0.264 | 1767 | 6.338 | 28.1 | 847 | 1.136 | 0.997 | 9.23 |
| Dozan, Balochistan | BOLAN-7 | 2374 | 0.917 | 0.472 | 8.28 | 0.126 | 706 | 1.402 | 9.17 | 278 | 0.274 | 0.204 | 5.08 |
| Dozan, Balochistan | BOLAN-8 | 2532 | 1.005 | 0.581 | 8.83 | 0.122 | 1179 | 1.764 | 20.88 | 290 | 0.356 | 0.248 | 5.27 |
| Dozan, Balochistan | BOLAN-9 | 2089 | 1.194 | 0.333 | 7.94 | 0.126 | 1098 | 1.94 | 19.77 | 169 | 0.271 | 0.24 | 7.12 |
| Dozan, Balochistan | BOLAN-10 | 2287 | 1.391 | 0.451 | 13.29 | 0.139 | 1554 | 2.461 | 13.14 | 309 | 0.425 | 0.299 | 9.14 |
| Mari nala, Jammu | JAMM-1 | 2273 | 0.201 | 0.433 | 4.01 | 0.067 | 1048 | 0.224 | 11.44 | 73 | 0.059 | 0.034 | 1.58 |
| Mari nala, Jammu | JAMM-2 | 5568 | 1.621 | 1.639 | 6.13 | 0.131 | 3253 | 1.33 | 115.8 | 550 | 0.863 | 0.195 | 4.02 |
| Mari nala, Jammu | JAMM-3 | 2672 | 0.504 | 0.472 | 2.26 | 0.069 | 825 | 0.305 | 10.09 | 90 | 0.11 | 0.044 | 1.46 |
| Mari nala, Jammu | JAMM-4 | 2535 | 0.243 | 0.497 | 2.72 | 0.082 | 724 | 0.294 | 8.05 | 79 | 0.094 | 0.034 | 1.37 |
| Mari nala, Jammu | JAMM-5 | 2582 | 3.948 | 0.345 | 2.34 | 0.104 | 476 | 2.527 | 8.91 | 282 | 0.615 | 0.396 | 1.28 |
| Jangleghari, Jammu | JAMM-6 | 4662 | 0.79 | 0.745 | 3.02 | 0.089 | 1144 | 0.559 | 12.34 | 219 | 0.335 | 0.105 | 2.96 |
| Jangleghari, Jammu | JAMM-7 | 3903 | 0.293 | 0.635 | 3.12 | 0.086 | 1321 | 0.26 | 17.7 | 285 | 0.291 | 0.073 | 4.08 |
| Jangleghari, Jammu | JAMM-8 | 5326 | 9.827 | 0.423 | 3.68 | 0.114 | 689 | 5.88 | 7.39 | 235 | 0.183 | 0.59 | 3.72 |
| Jangleghari, Jammu | JAMM-9 | 5251 | 2.345 | 0.858 | 4.22 | 0.117 | 1698 | 1.649 | 65.81 | 1388 | 0.707 | 0.272 | 6.15 |
| Jangleghari, Jammu | JAMM-10 | 2290 | 0.346 | 0.374 | 2.58 | 0.082 | 881 | 0.285 | 11.32 | 124 | 0.099 | 0.058 | 0.79 |

# APPENDIX 6.3

# ELEMENTAL CONCENTRATIONS FOR BLACK CHERT SAMPLES FROM SAKESAR LIMESTONE, SALT RANGE

(parts per million)

| Location | Sample | Al | Ce | Co | Cr | Eu | Fe | La | Mn | Na | Sc | Sm | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nammal Gorge, Salt Range | SRNG-1 | 2133 | 0.981 | 0.388 | 14.44 | 0.122 | 914 | 0.928 | 11.53 | 659 | 0.162 | 0.193 | 9.87 |
| Nammal Gorge, Salt Range | SRNG-2 | 2517 | 0.900 | 0.539 | 21.97 | 0.097 | 1442 | 0.874 | 9.84 | 477 | 0.215 | 0.181 | 21.00 |
| Nammal Gorge, Salt Range | SRNG-3 | 2282 | 0.771 | 0.453 | 15.13 | 0.103 | 1129 | 0.84 | 10.47 | 500 | 0.152 | 0.182 | 11.90 |
| Nammal Gorge, Salt Range | SRNG-4 | 2433 | 0.925 | 0.576 | 24.86 | 0.117 | 1801 | 0.958 | 12.46 | 377 | 0.267 | 0.187 | 38.88 |
| Nammal Gorge, Salt Range | SRNG-5 | 2204 | 1.063 | 0.437 | 16.90 | 0.117 | 1192 | 1.229 | 10.25 | 338 | 0.202 | 0.267 | 18.87 |
| Nammal Gorge, Salt Range | SRNG-6 | 2259 | 0.795 | 0.486 | 16.80 | 0.092 | 1166 | 0.913 | 14.48 | 482 | 0.197 | 0.157 | 19.38 |
| Nammal Gorge, Salt Range | SRNG-7 | 2474 | 0.912 | 0.518 | 16.90 | 0.074 | 1409 | 0.907 | 10.89 | 421 | 0.192 | 0.160 | 20.11 |
| Nammal Gorge, Salt Range | SRNG-8 | 2333 | 0.886 | 0.417 | 13.29 | 0.09 | 678 | 0.879 | 7.25 | 339 | 0.217 | 0.182 | 17.06 |
| Nammal Gorge, Salt Range | SRNG-9 | 2270 | 1.041 | 0.518 | 17.20 | 0.088 | 1085 | 1.061 | 14.99 | 431 | 0.241 | 0.186 | 18.95 |
| Nammal Gorge, Salt Range | SRNG-10 | 2179 | 0.645 | 0.661 | 26.57 | 0.092 | 2999 | 0.875 | 31.91 | 667 | 0.176 | 0.198 | 10.91 |
| Buri Khel, Salt Range | SRBK-6 | 2334 | 0.753 | 0.535 | 19.57 | 0.101 | 1587 | 0.678 | 18.73 | 322 | 0.184 | 0.146 | 12.53 |
| Buri Khel, Salt Range | SRBK-7 | 2200 | 1.002 | 0.476 | 14.61 | 0.129 | 913 | 0.658 | 8.58 | 349 | 0.192 | 0.149 | 12.07 |
| Buri Khel, Salt Range | SRBK-8 | 2386 | 1.108 | 0.423 | 14.44 | 0.113 | 913 | 0.799 | 9.51 | 333 | 0.214 | 0.200 | 11.69 |

# APPENDIX 6.4

# ELEMENTAL CONCENTRATIONS FOR TAN-GRAY CHERT ARTIFACTS FROM HARAPPA AND NAGWADA (BOTTOM ROW)

(parts per million)

| Figure 6.1 # | Artifact | Period | Trench | Al | Ce | Co | Eu | Fe | La | Mn | Na | Sc | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | H98/8482-13 | 1 | 39 | 2044 | 2.338 | 1.003 | 0.141 | 1748 | 1.170 | 11.01 | 644 | 0.268 | 7.52 | 23.01 |
| 12 | H96/7531-4 | 1 | 39 | 1914 | 3.021 | 0.513 | 0.126 | 1617 | 0.837 | 13.25 | 435 | 0.22 | 11.18 | 13.73 |
| 11 | H96/7500-30 | 1 | 39 | 2429 | 0.548 | 0.375 | 0.101 | 610 | 0.494 | 4.26 | 689 | 0.073 | 0.93 | 7.04 |
| 15 | H98/8429-24 | 2 | 39 | 8678 | 1.320 | 0.430 | 0.097 | 1228 | 0.714 | 33.43 | 439 | 0.231 | 3.34 | 37.24 |
| 13 | H2000/9984-12 | 2 | 39 | 1841 | 0.876 | 0.507 | 0.119 | 994 | 0.829 | 65.98 | 278 | 0.193 | 2.14 | 5.36 |
| 14 | H98/8417-1 | 2/3 | 39 | 1779 | 2.300 | 0.533 | 0.101 | 916 | 0.593 | 7.88 | 823 | 0.173 | 10.08 | 9.29 |
| 6 | H2000/2125-17 | 3A | 54 | 2054 | 3.038 | 0.879 | 0.076 | 1412 | 0.922 | 23.85 | 957 | 0.137 | 12.72 | 18.95 |
| 7 | H2000/2300-24 | 3A | 54 | 1794 | 4.124 | 0.419 | 0.140 | 737 | 1.048 | 19.25 | 583 | 0.169 | 18.06 | 7.74 |
| 9 | H2000/2312-27 | 3A | 54 | 1702 | 1.938 | 0.427 | 0.137 | 891 | 0.721 | 7.90 | 718 | 0.132 | 7.60 | 9.08 |
| 8 | H97/7781-46 | 3B | 42 | 2103 | 1.696 | 0.540 | 0.128 | 1030 | 0.775 | 21.07 | 374 | 0.239 | 5.31 | 5.44 |
| 10 | H97/7778-17 | 3B | 42 | 1853 | 1.754 | 0.375 | 0.073 | 769 | 0.503 | 8.01 | 520 | 0.139 | 8.04 | 6.60 |
| 1 | H2001/2939-27 | 3B | 54 | 1841 | 8.355 | 0.680 | 0.127 | 1142 | 1.505 | 7.64 | 617 | 0.162 | 30.94 | 31.91 |
| 2 | H2001/2920-77 | 3B | 54 | 1664 | 0.774 | 0.390 | 0.117 | 513 | 0.704 | 25.68 | 448 | 0.159 | 1.80 | 4.56 |
| 3 | H2001/2920-76 | 3B | 54 | 1746 | 6.947 | 0.429 | 0.099 | 644 | 1.398 | 3.34 | 699 | 0.165 | 28.08 | 14.81 |
| 4 | H2001/2943-7 | 3B | 54 | 1735 | 3.578 | 0.422 | 0.110 | 818 | 0.912 | 4.08 | 889 | 0.163 | 14.53 | 9.37 |
| NGW | NGW | Harappan | n/a | 8342 | 2.884 | 0.391 | 0.110 | 902 | 1.102 | 67.15 | 451 | 0.20 | 10 | 46.32 |

# APPENDIX 6.5

## ELEMENTAL CONCENTRATIONS FOR TAN-GRAY CHERT SAMPLES FROM FOUR ROHRI HILLS LOCATIONS

(parts per million)

| Location | Sample | Al | Ce | Co | Eu | Fe | La | Mn | Na | Sc | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adam Sultan | RHAS-1 | 2153 | 1.499 | 0.391 | 0.128 | 799 | 0.533 | 5.08 | 656 | 0.324 | 2.78 | 7.34 |
| Adam Sultan | RHAS-2 | 2186 | 1.003 | 0.461 | 0.126 | 1164 | 0.925 | 12.23 | 579 | 0.320 | 2.17 | 6.95 |
| Adam Sultan | RHAS-3 | 2150 | 1.198 | 0.437 | 0.061 | 1280 | 0.479 | 7.94 | 619 | 0.311 | 2.84 | 8.40 |
| Adam Sultan | RHAS-4 | 2356 | 1.116 | 0.514 | 0.150 | 1584 | 1.183 | 15.25 | 759 | 0.364 | 1.96 | 9.31 |
| Adam Sultan | RHAS-5 | 2228 | 1.051 | 0.455 | 0.080 | 1099 | 0.506 | 6.78 | 654 | 0.309 | 3.02 | 8.09 |
| Kot Diji | RHKD-1 | 2136 | 2.110 | 1.158 | 0.129 | 1588 | 1.076 | 72.28 | 292 | 0.325 | 4.32 | 10.88 |
| Kot Diji | RHKD-2 | 2213 | 1.938 | 0.477 | 0.136 | 933 | 1.173 | 23.57 | 413 | 0.521 | 2.50 | 13.20 |
| Kot Diji | RHKD-3 | 2532 | 1.286 | 2.019 | 0.103 | 5160 | 0.882 | 60.2 | 367 | 0.474 | 3.81 | 36.91 |
| Kot Diji | RHKD-4 | 1996 | 0.460 | 0.971 | 0.091 | 2517 | 0.541 | 12.77 | 544 | 0.366 | 1.69 | 19.19 |
| Kot Diji | RHKD-5 | 2357 | 2.172 | 0.967 | 0.155 | 1786 | 1.298 | 41.37 | 538 | 0.449 | 1.71 | 12.66 |
| Rohri | RHR-1 | 1737 | 0.777 | 0.355 | 0.116 | 1142 | 0.514 | 10.44 | 427 | 0.135 | 3.09 | 8.50 |
| Rohri | RHR-2 | 1622 | 5.648 | 0.469 | 0.076 | 1651 | 1.127 | 10.55 | 266 | 0.171 | 23.01 | 8.64 |
| Rohri | RHR-3 | 1721 | 1.509 | 0.535 | 0.116 | 2172 | 0.818 | 11.52 | 185 | 0.136 | 5.60 | 20.30 |
| Rohri | RHR-4 | 1892 | 1.280 | 0.523 | 0.093 | 2161 | 0.706 | 15.31 | 271 | 0.235 | 5.22 | 9.44 |
| Rohri | RHR-5 | 1572 | 1.279 | 0.493 | 0.084 | 1134 | 0.628 | 9.06 | 504 | 0.160 | 4.13 | 11.02 |
| Kandarki | RHK-1 | 1946 | 1.632 | 0.677 | 0.083 | 2009 | 0.448 | 22.88 | 225 | 0.244 | 6.47 | 9.79 |
| Kandarki | RHK-2 | 2071 | 1.643 | 0.762 | 0.072 | 2742 | 0.554 | 20.99 | 207 | 0.278 | 7.52 | 10.94 |
| Kandarki | RHK-3 | 2024 | 1.514 | 0.793 | 0.097 | 2812 | 0.503 | 28.13 | 257 | 0.268 | 6.37 | 10.62 |
| Kandarki | RHK-4 | 1979 | 1.349 | 0.892 | 0.101 | 3812 | 0.692 | 45.91 | 196 | 0.206 | 5.31 | 9.37 |
| Kandarki | RHK-5 | 2041 | 2.853 | 0.663 | 0.071 | 2057 | 0.819 | 16.86 | 229 | 0.246 | 13.12 | 10.84 |

# APPENDIX 6.6

# ELEMENTAL CONCENTRATIONS FOR TAN-GRAY CHERT SAMPLES FROM BALOCHISTAN, THE NWFP AND THE PUNJAB

(parts per million)

| Location | Sample | Al | Ce | Co | Eu | Fe | La | Mn | Na | Sc | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Balochistan - Kalat - Gunga | Aub138-1 | 12924 | 0.349 | 0.415 | 0.081 | 1046 | 0.315 | 40.15 | 218 | 0.073 | 0.28 | 6.86 |
| Balochistan - Kalat - Gunga | Aub138-2 | 13274 | 0.348 | 0.316 | 0.087 | 628 | 0.334 | 15.62 | 217 | 0.054 | 0.23 | 4.12 |
| Balochistan - Kalat - Gunga | Aub138-3 | 2624 | 0.737 | 0.536 | 0.102 | 1223 | 1.294 | 7.18 | 322 | 0.203 | 0.45 | 1.49 |
| Balochistan - Kalat - Gunga | Aub138-4 | 14108 | 0.580 | 0.527 | 0.110 | 1653 | 1.195 | 53.11 | 404 | 0.299 | 0.45 | 17.61 |
| Balochistan - Kalat - Gunga | Aub138-5 | 32205 | 3.268 | 2.264 | 0.156 | 4191 | 2.974 | 248.34 | 1410 | 1.336 | 1.37 | 66.87 |
| NWFP - Mohmand Agency | MMA-1 | 2221 | 2.839 | 0.702 | 0.104 | 1697 | 1.013 | 27.94 | 323 | 0.226 | 12.27 | 19.53 |
| NWFP - Mohmand Agency | MMA-2 | 1678 | 2.520 | 0.466 | 0.109 | 890 | 1.063 | 33.91 | 189 | 0.171 | 11.61 | 14.65 |
| NWFP - Mohmand Agency | MMA-3 | 1606 | 2.789 | 0.610 | 0.112 | 1286 | 1.015 | 34.32 | 176 | 0.158 | 11.01 | 14.12 |
| NWFP - Mohmand Agency | MMA-4 | 363 | 2.412 | 0.425 | 0.242 | 1566 | 2.160 | 4.07 | 190 | 0.217 | 4.91 | 2.72 |
| NWFP - Mohmand Agency | MMA-5 | 6738 | 1.099 | 0.369 | 0.127 | 925 | 1.260 | 85.85 | 141 | 0.169 | 2.00 | 23.73 |
| NWFP - Mohmand Agency | MMA-6 | 1569 | 1.933 | 0.381 | 0.130 | 732 | 1.124 | 16.96 | 136 | 0.161 | 4.72 | 5.75 |
| NWFP - Mohmand Agency | MMA-7 | 1841 | 2.352 | 0.572 | 0.110 | 1616 | 0.778 | 22.61 | 175 | 0.127 | 9.72 | 16.09 |
| NWFP - Mohmand Agency | MMA-8 | 1690 | 2.983 | 0.448 | 0.101 | 1124 | 1.045 | 29.59 | 217 | 0.188 | 10.65 | 21.79 |
| Punjab - Salt Range - Buri Khel | SRBK-1 | 2145 | 1.043 | 0.420 | 0.174 | 1782 | 1.231 | 12.24 | 197 | 0.149 | 0.98 | 8.26 |
| Punjab - Salt Range - Buri Khel | SRBK-2 | 1917 | 1.724 | 0.365 | 0.174 | 1436 | 2.008 | 14.28 | 159 | 0.230 | 1.02 | 6.22 |
| Punjab - Salt Range - Buri Khel | SRBK-3 | 2390 | 0.599 | 0.428 | 0.121 | 1159 | 0.589 | 9.46 | 229 | 0.146 | 0.79 | 9.32 |
| Punjab - Salt Range - Buri Khel | SRBK-4 | 2093 | 0.957 | 0.402 | 0.123 | 840 | 1.077 | 8.85 | 187 | 0.161 | 0.85 | 6.35 |
| Punjab - Salt Range - Buri Khel | SRBK-5 | 1973 | 0.895 | 0.402 | 0.120 | 1323 | 0.926 | 11.09 | 152 | 0.140 | 0.73 | 6.15 |

# APPENDIX 6.7

# STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS FOR FIGURES IN CHAPTER 6 GENERATED USING CANONICAL DISCRIMINANT ANALYSIS

| *Figure 6.18* | *Function 1* | *Function 2* |
|---|---|---|
| Log Al | -1.79 | -1.246 |
| Log Ce | 2.046 | -3.226 |
| Log Co | 1.299 | 1.036 |
| Log Cr | 0.949 | -0.693 |
| Log Eu | 0.496 | 0.569 |
| Log La | -1.596 | 3.698 |
| Log Mn | -0.733 | -0.056 |
| Log Sc | -0.312 | 0.007 |
| Log V | 0.82 | 0.339 |

| *Figure 6.30* | *Function 1* | *Function 2* |
|---|---|---|
| Log Al | 1.688 | 1.425 |
| Log Ce | .953 | -.993 |
| Log Co | .546 | -1.242 |
| Log Eu | -.530 | .256 |
| Log Fe | .594 | 1.213 |
| Log La | .289 | -.905 |
| Log Mn | -.933 | .320 |
| Log Na | .348 | .735 |
| Log Sc | -.285 | .809 |
| Log U | -1.321 | 1.738 |
| Log V | -1.217 | -2.230 |

| *Figure 6.31* | *Function 1* | *Function 2* |
|---|---|---|
| Log Al | .142 | 1.559 |
| Log Ce | -.401 | .361 |
| Log Co | -1.608 | -.877 |
| Log Eu | .204 | .068 |
| Log Fe | 1.190 | 1.502 |
| Log La | .125 | -.635 |
| Log Mn | .238 | -.373 |
| Log Na | .123 | .604 |
| Log Sc | -.865 | -.064 |
| Log U | 1.095 | .233 |
| Log V | -.157 | -1.386 |

## APPENDIX 7.1

## TYPE, CONTEXT AND CDA PREDICTION INFORMATION FOR THE UNFIRED STEATITE ARTIFACTS FROM HARAPPA ANALYZED FOR THIS STUDY (*BEAD BLANKS)

| Artifact (year/lot-record) | Type | Mound / Area | Trench / Op. | Period | CDA predicted group membership (PGM) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | full set 1st PGM | parent-rock 1st & 2nd PGM | 11 dolomitic 1st PGM | regional dolomitic 1st PGM |
| H87/33-02 | F | Cemetery | Op. 1 | 3C | SB | SB / SKK | SB | Sherwan |
| H87/86-228 | F | Cemetery | Op. 1 | 3C | SB | SB / JKK | SB | S.RAJ |
| H87/86-229 | F | Cemetery | Op. 1 | 3C | SB | SB / JKK | SB | S.RAJ |
| H87/86-236 | F | Cemetery | Op. 1 | 3C | SB | JKK / SB | SB | Sherwan |
| H87/237-86 | F | Cemetery | Op. 1 | S&D | SB | SB / ATM | SB | Sherwan |
| H88/340-24 | F | E | Op. 3 | S&D | PD | RKA / PD | PD | PD |
| H89/1018-13 | D | AB / E | 53 | S&D | SKK | SKK / SB | SKK | Sherwan |
| H89/1121-5 | A | E | 52 | S&D | SKK | SKK / SC | SKK | Sherwan |
| H2000/2230-14 | C | E | 54 | 3B | SB | SB / RSA | SB | Sherwan |
| H2000/2230-15 | C | E | 54 | 3B | SB | SB / LKPD | LKPD | LKPD |
| H2000/2230-16 | C | E | 54 | 3B | JAMPT | JAMPT / RSA | JAMPT | JAMPT |
| H2000/2230-17 | B | E | 54 | 3B | JAMPT | JAMPT / SB | JAMPT | Sherwan |
| H2000/2301-176* | B | E | 54 | 3A | SB | JAMPT / SB | JAMPT | Sherwan |
| H2000/2301-177* | B | E | 54 | 3A | JAMPT | JAMPT / SB | JAMPT | JAMPT |
| H2001/2373-10 | C | E | 54 | 3B | RSA | RSA / SB | SKK | Sherwan |
| H2000/2753-17 | E | E | 55 | 3C | SB | SB / PD | PD | PD |
| H2000/2774-14 | G | E | 55 | 3C | SKK | SC / SKK | SC | Sherwan |
| H2000/2774-15 | C | E | 55 | 3C | SB | PD / SKK | SKK | PD |
| H2000/2789-30 | C | E | 55 | 3C | SKK | SKK / SB | SKK | Sherwan |
| H2000/2880-16 | D | E | 55 | 3C | ATM | ATM / RSA | SKK | JAMPT |
| H2001/2913-12 | E | E | 57 | 3B | SKK | SKK / SB | SKK | Sherwan |
| H2001/2920-7 | C | E | 57 | S&D | SB | SB / SKK | SKK | Sherwan |
| H2001/2922-6 | A | E | 57 | S&D | SB | SB / SKK | SB | Sherwan |
| H2001/2939-25 | G | E | 57 | 3B | LKPD | JAMPT / BESH | LKPD | LKPD |
| H90/3030-55 | E | E | 58 | S&D | JAMPT | JAMPT / RSA | JAMPT | Sherwan |
| H90/3068-50 | A | E | 58 | S&D | SB | SB / RSA | SB | PD |
| H90/3290-17 | D | E | 59 | S&D | SB | SB / SKK | SB | Sherwan |
| H93/3534-13 | F | E | 2 | S&D | SKK | RSA / SB | LKPD | Sherwan |
| H93/3710-16 | F | E | 3 | 3C | SB | SB / SKK | SB | Sherwan |
| H93/3710-70 | F | E | 3 | 3C | SB | JKK / SB | LKPD | LKPD |
| H93/3808-52 | A | E | 5 | S&D | SB | SB / SKK | SKK | Sherwan |
| H93/3869-24 | A | E | 7 | 3C | SB | PD / SB | SKK | PD |
| H95/4453-22 | D | E | 11 | S&D | SB | SB / SKK | SB | Sherwan |

| Artifact (year/lot-record) | Type | Mound / Area | Trench / Op. | Period | CDA predicted group membership (PGM) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | full set 1st PGM | parent-rock 1st & 2nd PGM | 11 dolomitic 1st PGM | regional dolomitic 1st PGM |
| H95/4613-42 | A | ET | 10 | 3B | SB | SKK / SB | SKK | Sherwan |
| H95/4615-94 | A | ET | 10 | 3C | SB | SKK / SB | SKK | Sherwan |
| H95/4723-2 | B | ET | 19 | 3C | SB | LKPD / RDP | LKPD | LKPD |
| H95/4726-101 | A | ET | 19 | 3C | LKPD | SB / PD | SB | PD |
| H95/4746-7 | A | ET | 19 | 3C | SB | SB / PD | SB | PD |
| H95/4751-8 | E | ET | 19 | 3C | SB | LKPD / ATM | SKK | Sherwan |
| H95/4919-62 | D | ET | 28 | 3C | ATM | RDP / SC | RDP | Jhunjhunu |
| H95/4950-4 | A | ET | 28 | 3C | RDP | SB / SKK | SKK | Sherwan |
| H95/4954-18 | E | ET | 28 | 3C | SB | SB / SKK | SKK | Sherwan |
| H95/4961-176 | A | ET | 28 | 3C | SB | SB / SKK | SKK | Sherwan |
| H94/5135-34 | E | E | 7 / 8 | 3C | SB | SB / SKK | SB | Sherwan |
| H95/5184-1 | A | E | 7 / 8 | 3C | SB | SB / SKK | SB | Sherwan |
| H95/5713-145 | C | ET | 32 | S&D | SB | SB / PD | SB | Sherwan |
| H95/5734-31 | C | ET | 32 | 3C | SB | PD / SB | PD | PD |
| H95/5747-125 | B | ET | 32 | 3C | PD | SB / SKK | SB | Sherwan |
| H95/5749-97 | C | ET | 32 | 3C | SB | RSA / SB | SKK | Sherwan |
| H95/5759-25 | E | ET | 32 | 3C | SB | SB / PD | SB | PD |
| H95/5763-19 | A | ET | 32 | 3C | SB | SB / SKK | SB | Sherwan |
| H95/5802-5 | A | ET | 28 | 3C | SB | LKPD / BESH | LKPD | LKPD |
| H95/5803-25 | B | ET | 28 | 3C | LKPD | LKPD / BESH | LKPD | LKPD |
| H95/5820-11a | A | ET | 28 | 3C | LKPD | PD / SB | PD | PD |
| H96/5837-18 | B | ET | 28 | 3C | PD | SB / LKPD | SB | LKPD |
| H96/6218-8 | C | ET | 35 | S&D | LKPD | SKK / PD | SKK | PD |
| H96/6219-44 | D | ET | 35 | S&D | SB | SB / LKPD | SB | Sherwan |
| H96/6234-2 | C | ET | 35 | S&D | SB | SB / SKK | SB | Sherwan |
| H96/6257-21 | A | ET | 35 | 3C | SB | SB / SKK | SKK | Sherwan |
| H95/6509-97 | B | E / ET | 11 | 2 | SB | JAMPT / RSA | JAMPT | JAMPT |
| H96/7105-8 | A | E | 36 | 3C | JAMPT | SKK / SB | SKK | Sherwan |
| H96/7106-27 | G | E | 36 | 3C | SKK | LKPD / RDP | LKPD | LKPD |
| H96/7118-9 | A | E | 36 | 3C | LKPD | LKPD / BESH | LKPD | LKPD |
| H96/7153-14 | D | E | 36 | S&D | LKPD | SB / SKK | SB | Sherwan |
| H96/7156-14 | G | E | 36 | 3C | SB | SB / LKPD | SB | Sherwan |
| H96/7239-26 | A | F | 37 | 3C | SB | SB / SKK | SB | Sherwan |
| H96/7256-43 | B | F | 37 | 3B | SB | SKK / SB | SKK | Sherwan |
| H96/7257-46* | B | F | 37 | 3B | SKK | PD / SB | PD | PD |
| H96/7333-22 | A | AB | 38 | 5 | PD | SC / SC | SC | Sherwan |
| H96/7358-11 | A | AB | 38 | 5 | SC | LKPD / SKK | LKPD | LKPD |
| H96/7401-63 | F | AB | 39 | S&D | SC | SC / RDP | SC | Sherwan |

| Artifact (year/lot-record) | Type | Mound / Area | Trench / Op. | Period | CDA predicted group membership (PGM) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | full set 1st PGM | parent-rock 1st & 2nd PGM | 11 dolomitic 1st PGM | regional dolomitic 1st PGM |
| H96/7410-1 | E | AB | 39 | 2/3A | SKK | SKK / SB | SKK | Sherwan |
| H96/7410-2 | E | AB | 39 | 2/3A | SKK | SKK / SB | SKK | Sherwan |
| H96/7414-46 | A | AB | 39 | 2 | SC | SC / SKK | SC | Sherwan |
| H96/7414-47 | A | AB | 39 | 2 | JAMPT | JAMPT / LKPD | JAMPT | JAMPT |
| H96/7467-658* | A | AB | 39 | S&D | SKK | SB / JJG | ATM | S.RAJ |
| H96/7467-790 | A | AB | 39 | S&D | RSA | RDA / SKK | SKK | Sherwan |
| H96/7531-16 | A | AB | 39 | 1 | ATM | ATM / SB | ATM | Sherwan |
| H97/7619-3 | C | F | 41 | 3C | SB | SB / LKPD | SB | Sherwan |
| H99/7636-8 | E | F | 41 | 3C | JJK | JKK / ATM | RSA | Jhunjhunu |
| H99/7637-32 | G | F | 41 | 3C | JJK | JKK / RDP | LKPD | Jhunjhunu |
| H99/7638-1 | G | F | 41 | 3C | JJK | JKK / ATM | SB | Sherwan |
| H99/7649-42 | A | F | 41 | 3C | SB | SB / SKK | SB | Sherwan |
| H97/7780-10 | E | AB | 42 | 3B | SC | SC / SC | SB | Sherwan |
| H97/7780-8 | A | AB | 42 | 3B | SC | SC / SC | SC | Sherwan |
| H97/7780-9 | A | AB | 42 | 3B | SB | SB / SKK | SB | Sherwan |
| H97/7784-156 | A | AB | 42 | 3A | SKK | SKK / SC | SKK | Sherwan |
| H97/7784-157 | F | AB | 42 | 3A | RSA | RSA / LKPD | LKPD | LKPD |
| H97/7784-158 | A | AB | 42 | 3A | LKPD | LKPD / SB | LKPD | LKPD |
| H97/7784-159 | A | AB | 42 | 3A | SC | SC / SKK | SKK | Sherwan |
| H97/7784-16 | A | AB | 42 | 3A | RSA | RDA / SKK | RSA | Sherwan |
| H97/7784-17 | A | AB | 42 | 3A | JAMPT | JAMPT / SKK | SKK | JAMPT |
| H97/7784-18 | A | AB | 42 | 3A | USK | USK / SKK | USK | Uttaranchal |
| H97/7784-19 | A | AB | 42 | 3A | SC | SC / SKK | SC | Sherwan |
| H97/7784-20 | A | AB | 42 | 3A | USK | USK / SKK | USK | Sherwan |
| H97/7784-21 | B | AB | 42 | 3A | SB | SB / SKK | SB | Sherwan |
| H97/7784-22 | C | AB | 42 | 3A | JAMPT | JAMPT / SB | JAMPT | JAMPT |
| H97/7784-23 | C | AB | 42 | 3A | SB | SB / SKK | SKK | Sherwan |
| H97/7784-24 | C | AB | 42 | 3A | SKK | SKK / UB | SKK | Sherwan |
| H97/7784-25 | A | AB | 42 | 3A | JAMPT | JAMPT / SKK | SKK | JAMPT |
| H97/7784-27 | A | AB | 42 | 3A | LBW1 | LBW1 / LBW2 | - | - |
| H97/7784-28 | B | AB | 42 | 3A | SB | SB / SKK | SB | Sherwan |
| H97/7784-29 | B | AB | 42 | 3A | SC | LKPD / SC | SC | JAMPT |
| H97/7784-30 | E | AB | 42 | 3A | SB | SB / SKK | SKK | Sherwan |
| H97/7784-31 | F | AB | 42 | 3A | SC | SC / RDP | SC | LKPD |
| H99/7794-3 | B | AB | 42 | 3C | SB | SB / LKPD | SB | Sherwan |
| H98/8342-3 | F | AB | 39 | 3C | SC | SB / LKPD | SB | Sherwan |
| H98/8355-2 | A | AB | 39 | 3B | SB | SC / SKK | SC | Sherwan |
| H98/8364-5 | F | AB | 39 | 3B | SB | SB / SKK | SKK | Sherwan |
| H98/8407-39 | E | AB | 39 | 2 | RSA | SB / SC | SB | Sherwan |
| H98/8407-40 | A | AB | 39 | 2 | SC | RSA / USK | RDP | Uttaranchal |
| H98/8410-12 | A | AB | 39 | 2 | SC | SC / SKK | SC | Sherwan |

| Artifact (year/lot-record) | Type | Mound / Area | Trench / Op. | Period | CDA predicted group membership (PGM) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | full set 1st PGM | parent-rock 1st & 2nd PGM | 11 dolomitic 1st PGM | regional dolomitic 1st PGM |
| H98/8486-50 | A | AB | 39 | 2 | SKK | SC / SKK | SC | Sherwan |
| H98/8487-32 | E | AB | 39 | 2 | JAMPT | SKK / SC | SKK | Sherwan |
| H98/8487-33 | A | AB | 39 | 2 | PD | JAMPT / USK | JAMPT | JAMPT |
| H99/8490-103 | B | AB | 39 | 2 | SC | PD / SKK | PD | PD |
| H99/8492-229 | E | AB | 39 | 2 | SKK | SC / SKK | SC | Sherwan |
| H99/8497-3 | E | AB | 39 | 2 | LKPD | SKK / SC | SKK | Sherwan |
| H98/8668-2* | E | F | 43 | 3C | KOT | KOT / ZTT | - | - |
| H99/8760-77 | F | F | 43 | 3C | ATM | ATM / JKK | ANB | Jhunjhunu |
| H99/8956-1 | A | AB | 39 | 2 | JAMPT | JAMPT / USK | SKK | Sherwan |
| H2000/8983-44 | E | AB | 39 | 2 | LKPD | LKPD / SC | SC | Sherwan |
| H2000/8992-1 | E | AB | 39 | 2 | JAMPT | JAMPT / RSA | JAMPT | JAMPT |
| H2000/8997-4 | A | AB | 39 | 2 | JAMPT | JAMPT / USK | JAMPT | JAMPT |
| H2000/9442-2 | E | AB | 39 | 3B | SC | UB / SC | SC | Sherwan |
| H2000/9443-6 | A | AB | 39 | 3B | SKK | SKK / SC | SKK | Sherwan |
| H2000/9443-7 | B | AB | 39 | 3B | JAMPT | JAMPT / RSA | JAMPT | JAMPT |
| H2000/9445-1 | G | AB | 39 | 3B | ANB | ANB / ATM | ANB | Jhunjhunu |
| H2000/9445-2 | G | AB | 39 | 3B | LKPD | LKPD / SC | SC | LKPD |
| H2000/9447-5 | A | AB | 39 | 3B | SKK | SKK / SC | SC | Sherwan |
| H2000/9514-93 | E | AB | 39 | 2 | JAMPT | JAMPT / SB | SB | JAMPT |
| H99/9737-22 | A | F | 43 | 3C | SB | SB / PD | SKK | PD |
| H99/9747-33 | B | F | 43 | 3C | SB | SKK / SB | SKK | Sherwan |
| H99/9756-16 | A | F | 43 | 3C | SB | SB / SKK | SB | Sherwan |
| H99/9779-4 | A | F | 43 | 3C | SB | SB / LKPD | SB | Sherwan |
| H2000/9840-8 | E | F | 43 | 3C | SB | SB / SC | SB | Sherwan |
| H2000/9973-13 | C | AB | 39 | 2 | JAMPT | JAMPT / RSA | JAMPT | JAMPT |
| H2000/11001-6 | A | AB | 39 | 1 | JAMPT | JAMPT / RSA | JAMPT | JAMPT |
| H2001/11562-26 | F | E | 11 | S&D | SB | ATM / SB | SB | Sherwan |
| H2001/11923-9 | C | E | 11 | 3C | SB | SB / PD | SB | Sherwan |
| H90/3208-68** | A | E | 59 | 3C | PD | PD/DGT | PD | PD |

# APPENDIX 7.2

## STEATITE DEPOSITS IN PAKISTAN AND INDIA SAMPLED FOR THIS STUDY

| Region | District / Agency | Deposit | Source code | Coordinates | Parent-Rock |
|---|---|---|---|---|---|
| Balochistan | Las Bela | Wayaro 1 (Duddo mine) | LBW1 | ≈ N 26° 02', E 66° 39' | Ultramafic |
| Balochistan | Las Bela | Wayaro 2 (Thaddi mine) | LBW2 | ≈ N 26° 00', E 66° 37' | Ultramafic |
| Balochistan | Zhob | Urgasai Nasir, Muslimbagh Ophiolite | ZUN | ≈ N 30° 52', E 67° 39' | Ultramafic |
| Balochistan | Zhob | Takhahen, Muslimbagh Ophiolite | ZTAK | ≈ N 30° 43', E 67° 52' | Ultramafic |
| Balochistan | Zhob | Tor Tangi, Muslimbagh Ophiolite | ZTT | ≈ N 30° 56', E 67° 49' | Ultramafic |
| FATA | Kurram | Safed Koh (Parachinar-Daradar) | PD | ≈ N 33° 57', E 70° 14' | Dolomite |
| FATA | Mohmand | Sakhakot-Qila Ophiolite (Kot) | KOT & Kot (MP) | ≈ N 34° 27', E 71° 43' | Ultramafic |
| FATA | Khyber | Landi Kotal (Prang Dera) | LKPD | ≈ N 34° 00', E 71° 05' | Dolomite |
| NWFP | Swat | Tangir mine (Besham-Derai area) | BESH | ≈ N 35° 55', E 72° 50' | Dolomite |
| NWFP | Hazara | Sherwan - Khanda Khu | SKK | ≈ N 34° 11', E 73° 03' | Dolomite |
| NWFP | Hazara | Sherwan - Bandi | SB | ≈ N 34° 12', E 73° 02' | Dolomite |
| NWFP | Hazara | Sherwan - Chelethar | SC | ≈ N 34° 12', E 73° 02' 30" | Dolomite |
| NWFP | Chitral | near Tar village, Shi Shi Valley | CHT | ≈ N 35° 43', E 71° 57' | Ultramafic |
| Jammu | Udhampur | Painthal | JAMPT | N 32° 59.695, E 74° 59.097 | Dolomite |
| Uttaranchal | Bageshwar | Chatikhet to Dungri to Kanda | UB | N 29° 52.286, E 79° 51.198 | Dolomite |
| Uttaranchal | Bageshwar | Saling | US | N 30° 01.086, E 79° 56.742 | Dolomite |
| Uttaranchal | Bageshwar | Shishi Khani | USK | N 29° 48.678, E 79° 46.374 | Dolomite |
| Gujarat | Sarbarkantha | Dev Mori – Bhiloda & Kundol | DMB & DMK | N 23° 36.276, E 73° 23.050 | Ultramafic |
| Gujarat | Panchmahal | Gandhra | GPM | N 22° 27.449, E 73° 41.372 | Dolomite |

| Region | District / Agency | Deposit | Source code | Coordinates | Parent-Rock |
|---|---|---|---|---|---|
| Rajasthan | Alwar | Nangalhari-Bairaswas | ANB | N 27° 27.003, E 76° 24.209 | Dolomite |
| Rajasthan | Alwar | Samra | ASM | N 27° 11.254, E 76° 13.929 | Dolomite |
| Rajasthan | Alwar | Teori | ATM | N 27° 24.070, E 76° 08.880 | Dolomite |
| Rajasthan | Jaipur | Degota | DGT | N 27° 06.122, E 76° 14.995 | Dolomite |
| Rajasthan | Jhunjhunu | Chirani-ki-Dhani | JJC | N 28° 00.643, E 75° 48.522 | Dolomite |
| Rajasthan | Jhunjhunu | Gurda | JJG | N 27° 48.847, E 75° 38.419 | Dolomite |
| Rajasthan | Jhunjhunu | Kho | JJK | N 27° 47.218, E 75° 37.948 | Dolomite |
| Rajasthan | Dungarpur | Deola | RDP | N 23° 53.762, E 74° 21.052 | Dolomite |
| Rajasthan | Dungarpur | Manpur | RMP | N 23° 51.328, E 73° 45.714 | Ultramafic |
| Rajasthan | Dungarpur | Shala Shah Thana | RST | N 24° 03.222, E 73° 40.115 | Ultramafic |
| Rajasthan | Rajsamand | Karoli | RKA | N 24° 51.731, E 73° 45.499 | Dolomite |
| Rajasthan | Rajsamand | Rabcha | RRA | N 24° 53.786, E 73° 47.074 | Dolomite |
| Rajasthan | Udaipur | Dev Pura | RDV | N 24° 18.182, E 73° 46.715 | Dolomite |
| Rajasthan | Udaipur | Kali Ghadi mine | RKG | ≈ N 24° 07', E 73° 40' | Ultramafic |
| Rajasthan | Udaipur | Rishab-der | RRD | ≈ N 24° 02', E 73° 38' | Ultramafic |
| Rajasthan | Udaipur | near Salumbar | RSA | N 24° 07.204, E 74° 07.356 | Dolomite |
| Rajasthan | Udaipur | Shiv Bola mine | RSB | ≈ N 24° 03', E 73° 38' | Ultramafic |
| Rajasthan | Udaipur | Khadi Ghati mine | RSH | ≈ N 23° 59', E 73° 47' | Ultramafic |

# APPENDIX 7.3

# INAA DATA FOR STEATITE SAMPLES COLLECTED FROM DEPOSITS IN PAKISTAN AND INDIA.

Data in parts per million (PPM)

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ANB-01 | 10838 | 3.9488 | 10.59 | 0.05794 | 11394 | 0.11851 | 19.309 | 8070.88 | 0.0914 | 14.73 | 51.54 |
| ANB-02 | 3132 | 7.3863 | 18.501 | 0.09754 | 16045 | 0.45252 | 29.321 | 1535.31 | 1.0496 | 27.033 | 41.686 |
| ANB-03 | 8829 | 5.6125 | 27.046 | 0.09216 | 13640 | 0.73486 | 29.457 | 6347.02 | 0.8313 | 34.387 | 27.745 |
| ANB-04 | 7410 | 5.8687 | 14.154 | 0.10109 | 13597 | 0.66108 | 24.943 | 5285.76 | 0.3912 | 28.835 | 37.634 |
| ANB-05 | 3091 | 3.4451 | 26.685 | 0.43534 | 11673 | 7.81245 | 25.551 | 74367.16 | 0.3194 | 14.189 | 20.415 |
| ANB-06 | 22469 | 0.3813 | 2.237 | 0.3038 | 70 | 0.48679 | 17.283 | 18026.28 | 0.0108 | 11.905 | 14.381 |
| ANB-07 | 4773 | 4.4095 | 7.093 | 0.08936 | 14249 | 0.18589 | 26.341 | 3288.62 | 0.3825 | 13.995 | 45.756 |
| ANB-08 | 6040 | 5.0426 | 13.26 | 0.09656 | 14669 | 0.35191 | 23.527 | 5162.58 | 0.2676 | 14.967 | 47.48 |
| ANB-09 | 2328 | 4.5184 | 6.484 | 0.10308 | 15652 | 0.12945 | 30.896 | 1238.02 | 0.7509 | 12.448 | 46.318 |
| ANB-10 | 1749 | 6.296 | 2.247 | 0.08499 | 15789 | 0.25353 | 26.296 | 613.34 | 0.2643 | 14.709 | 45.772 |
| ASM-01 | 5041 | 62.0628 | 2.915 | 0.23708 | 38576 | 3.89395 | 119.895 | 607.59 | 6.1815 | 21.671 | 37.106 |
| ASM-02 | 6884 | 82.9666 | 2.914 | 0.06382 | 37394 | 0.12002 | 53.078 | 900.75 | 2.4121 | 15.407 | 33.901 |
| ASM-03 | 6102 | 52.2559 | 1.932 | 0.89868 | 38991 | 16.74099 | 80.896 | 656.7 | 7.9921 | 27.205 | 12.812 |
| ASM-04 | 2822 | 51.9297 | 2.884 | 0.26342 | 29682 | 0.06561 | 49.394 | 473.77 | 1.4676 | 11.472 | 68.865 |
| ASM-05 | 41383 | 72.0259 | 49.15 | 0.21734 | 65274 | 0.44792 | 218.157 | 660.62 | 29.7642 | 166.489 | 137.797 |
| ASM-06 | 2960 | 53.3159 | 3.713 | 0.31987 | 30370 | 0.11255 | 55.553 | 459.96 | 1.4998 | 12.165 | 70.003 |
| ASM-07 | 4970 | 66.6679 | 3.141 | 0.27488 | 41526 | 0.21308 | 80.665 | 586.59 | 5.0374 | 23.166 | 87.085 |
| ASM-08 | 33971 | 20.3045 | 5.084 | 0.32132 | 41635 | 4.06409 | 97.341 | 14805.97 | 4.1106 | 26.794 | 84.438 |
| ASM-09 | 7119 | 82.8355 | 3.964 | 0.13809 | 38061 | 0.16251 | 55.816 | 974.15 | 3.1366 | 14.85 | 84.884 |
| ASM-10 | 65164 | 22.2235 | 3.077 | 1.60397 | 38030 | 2.13848 | 124.022 | 25641.84 | 25.3054 | 72.457 | 142.649 |
| ATM-01 | 1677 | 6.2143 | 2.813 | 0.07908 | 20473 | 0.22484 | 25.001 | 390.68 | 0.3548 | 5.183 | 6.095 |
| ATM-02 | 5810 | 2.1351 | 14.64 | 0.09001 | 32356 | 0.31447 | 41.247 | 3644.99 | 0.6938 | 7.196 | 6.275 |
| ATM-03 | 5159 | 14.9285 | 10.38 | 0.07973 | 28458 | 0.27459 | 22.405 | 3328.93 | 0.6876 | 12.313 | 3.8 |
| ATM-04 | 3889 | 1.5232 | 15.73 | 0.05143 | 31239 | 0.16566 | 35.516 | 2273.82 | 0.7773 | 7.15 | 22.18 |
| ATM-05 | 6721 | 3.3619 | 17.187 | 0.04968 | 26144 | 0.29461 | 41.465 | 3225.97 | 0.52 | 9.717 | 32.15 |
| ATM-06 | 5730 | 2.6302 | 18.141 | 0.07411 | 26532 | 0.14313 | 38.372 | 3462.39 | 0.708 | 7.576 | 29.552 |
| ATM-07 | 9607 | 1.5114 | 5.15 | 0.17968 | 20752 | 0.39987 | 30.897 | 6358 | 3.2441 | 25.09 | 35.433 |
| ATM-08 | 2768 | 2.8818 | 15.25 | 0.32287 | 21113 | 4.71459 | 25.715 | 1228.56 | 1.3072 | 4.128 | 98.035 |
| ATM-09 | 3756 | 2.9824 | 19.677 | 0.06657 | 23758 | 0.2293 | 33.263 | 1789.4 | 0.5454 | 6.506 | 139.586 |
| ATM-10 | 8376 | 1.9656 | 21.103 | 0.09169 | 33995 | 0.27174 | 47.483 | 5491.45 | 0.6311 | 12.428 | 52.167 |
| BESH-01 | 2239 | 8.139 | 6.345 | 0.05292 | 14530 | 0.2215 | 82.44 | 219.3 | 0.1118 | 4.788 | 568.6 |
| BESH-02 | 2257 | 6.908 | 2.858 | 0.05239 | 11990 | 0.2898 | 87.76 | 179.2 | 0.189 | 5.007 | 434.8 |
| BESH-03 | 3139 | 2.064 | 2.489 | 0.04839 | 8117 | 0.3212 | 48.53 | 139.2 | 0.0947 | 2.744 | 531.9 |
| BESH-04 | 71670 | 11.02 | 8.56 | 0.04323 | 44940 | 0.3287 | 487.6 | 296.5 | 0.5624 | 55.65 | 1296 |
| BESH-05 | 3643 | 1.865 | 1.965 | 0.03865 | 2861 | 0.1833 | 9.407 | 279.7 | 0.2165 | 2.726 | 43 |
| BESH-06 | 3445 | 1.464 | 1.382 | 0.03483 | 5227 | 0.1617 | 54.12 | 165.7 | 0.0633 | 3.581 | 385.8 |
| CHT-05 | 105750 | 20.1943 | 120.602 | 0.27555 | 19625 | 0.55821 | 939.388 | 611.05 | 9.7798 | 38.55 | 13.247 |
| CHT-06 | 5938 | 116.4152 | 2884.07 | 0.08195 | 43116 | 0.43713 | 486.602 | 166.03 | 3.8576 | 24.764 | 15.172 |
| CHT-07 | 4602 | 100.327 | 2201.815 | 0.08196 | 41532 | 0.83485 | 513.342 | 185.47 | 4.4241 | 20.801 | 11.143 |
| CHT-08 | 3309 | 95.8852 | 1084.921 | 0.2157 | 42565 | 1.35871 | 1069.746 | 136.54 | 6.9632 | 18.399 | 13.617 |
| CHT-09 | 7353 | 118.8686 | 2890.156 | 0.19991 | 42785 | 0.38929 | 538.488 | 134.39 | 6.8112 | 49.121 | 16.443 |
| CHT-10 | 10114 | 101.4568 | 2551.579 | 0.08495 | 35019 | 0.81213 | 502.177 | 136.86 | 3.29 | 27.145 | 12.231 |
| CHT-11 | 107126 | 79.1107 | 130.3 | 0.06972 | 57412 | 0.0254 | 995.937 | 154.67 | 2.2985 | 9.9 | 20.765 |
| CHT-12 | 4467 | 94.7426 | 2246.069 | 0.08479 | 39322 | 0.43779 | 470.692 | 161.75 | 3.3723 | 22.757 | 12.124 |
| CHT-13 | 107120 | 47.0076 | 854.304 | 0.09972 | 30458 | 0.77108 | 1113.708 | 222.22 | 25.6847 | 73.995 | 16.853 |
| CHT-14 | 114231 | 39.0685 | 585.932 | 0.13376 | 30470 | 1.82156 | 1172.146 | 179.6 | 23.9586 | 77.056 | 16.036 |
| CHT-15 | 107996 | 17.6785 | 93.941 | 0.14288 | 17011 | 0.13516 | 981.748 | 4771.21 | 6.0683 | 23.332 | 15.953 |
| CHT-16 | 7886 | 52.5927 | 1001.07 | 0.05159 | 36690 | 0.15301 | 289.861 | 131.79 | 5.6678 | 29.849 | 8.673 |
| CHT-17 | 5249 | 92.6355 | 3230.896 | 0.19414 | 49392 | 0.24402 | 501.981 | 149.64 | 4.1732 | 32.134 | 14.29 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CHT-18 | 6080 | 108.8336 | 2335.358 | 0.31449 | 41961 | 0.39644 | 523.869 | 130.7 | 6.6138 | 34.36 | 15.347 |
| CHT-19 | 5240 | 96.6386 | 3822.27 | 0.21664 | 48799 | 0.38621 | 519.646 | 138.69 | 3.6297 | 29.835 | 24.565 |
| CHT-20 | 1521 | 27.1111 | 399.325 | 0.22573 | 17480 | 0.02248 | 147.894 | 203.58 | 2.3574 | 4.388 | 8.673 |
| DGT-01 | 10669 | 6.0233 | 13.351 | 0.18205 | 8559 | 0.28125 | 21.665 | 226.72 | 4.3521 | 15.589 | 7.858 |
| DGT-02 | 6703 | 7.6544 | 4.305 | 0.1176 | 13183 | 0.11123 | 38.973 | 237.82 | 2.5701 | 12.083 | 7.886 |
| DGT-03 | 9187 | 6.469 | 11.263 | 0.10631 | 6614 | 0.19383 | 23.168 | 206.25 | 2.3182 | 12.165 | 6.9 |
| DGT-04 | 16087 | 14.8073 | 10.463 | 0.08876 | 17581 | 0.28503 | 43.289 | 235.76 | 5.5005 | 28.033 | 9.31 |
| DGT-05 | 7106 | 4.67 | 7.774 | 0.15633 | 3893 | 0.29221 | 21.524 | 219.67 | 1.8603 | 10.558 | 6.297 |
| DGT-06 | 8457 | 4.861 | 7.84 | 0.09832 | 4156 | 0.04864 | 13.788 | 222.64 | 2.0799 | 13.015 | 3.478 |
| DGT-07 | 3448 | 9.2071 | 3.588 | 0.11251 | 14814 | 0.14959 | 44.825 | 312.87 | 1.1908 | 6.467 | 7.178 |
| DGT-08 | 2883 | 6.9818 | 0.829 | 0.10871 | 6783 | 0.03726 | 18.495 | 265.13 | 1.0948 | 5.572 | 6.274 |
| DGT-09 | 10254 | 15.5073 | 11.945 | 0.12889 | 17041 | 0.2382 | 33.675 | 250.97 | 3.7338 | 16.161 | 48.875 |
| DGT-10 | 9762 | 5.0405 | 12.938 | 0.17957 | 4672 | 2.44249 | 9.477 | 240.51 | 3.0705 | 13.624 | 55.805 |
| DMB-01 | 9513 | 84.7546 | 1426.757 | 0.14157 | 27827 | 0.14541 | 126.587 | 137.19 | 4.714 | 20.145 | 84.789 |
| DMB-02 | 7540 | 86.5644 | 1286.542 | 0.09382 | 28275 | 0.13249 | 122.483 | 236.04 | 3.9437 | 18.922 | 83.137 |
| DMK-01 | 9025 | 50.7741 | 941.29 | 0.06221 | 19443 | 0.03357 | 398.081 | 108.67 | 3.0674 | 24.211 | 9.745 |
| DMK-02 | 3126 | 55.953 | 923.911 | 0.10377 | 23669 | 0.10086 | 175.869 | 157.69 | 2.7086 | 12.054 | 10.73 |
| DMK-03 | 1945 | 64.8495 | 187.698 | 0.08588 | 28092 | 0.04729 | 246.996 | 167.09 | 0.7702 | 3.661 | 23.205 |
| DMK-04 | 7331 | 67.5889 | 1095.566 | 0.12478 | 29451 | 0.02708 | 276.361 | 140.55 | 1.4461 | 16.281 | 18.978 |
| DMK-05 | 9726 | 72.9098 | 1291.936 | 0.08284 | 30920 | 0.03825 | 277.173 | 187.79 | 5.7345 | 22.016 | 11.968 |
| DMK-06 | 6589 | 77.828 | 1126.932 | 0.09159 | 32582 | 0.03555 | 257.156 | 159.3 | 5.273 | 18.443 | 11.963 |
| DMK-07 | 6328 | 60.0072 | 1370.227 | 0.11073 | 32866 | 0.05718 | 226.01 | 147.65 | 5.8568 | 23.149 | 11.444 |
| DMK-08 | 5029 | 87.129 | 1631.007 | 0.13266 | 30083 | 0.05934 | 278.276 | 157.09 | 3.1263 | 17.79 | 13.005 |
| DMK-10 | 3828 | 96.9284 | 1628.703 | 0.08653 | 32379 | 0.04035 | 253.713 | 162.39 | 3.3557 | 15.465 | 12.12 |
| DMK-11 | 6680 | 90.6609 | 1716.564 | 0.11786 | 37669 | 0.05292 | 310.524 | 175.81 | 5.1705 | 29.491 | 102.259 |
| DMK-12 | 18079 | 74.7236 | 2491.719 | 0.09747 | 38212 | 0.07968 | 386.375 | 120.61 | 5.6655 | 38.142 | 100.534 |
| DMK-13 | 6697 | 96.1327 | 1494.2 | 0.0863 | 33717 | 0.08049 | 319.308 | 161.22 | 4.7049 | 15.306 | 102.422 |
| DMK-14 | 6098 | 90.6916 | 1671.748 | 0.08014 | 36766 | 0.07244 | 318.308 | 149.75 | 4.6683 | 29.821 | 57.39 |
| DMK-15 | 7713 | 83.6133 | 1541.921 | 0.08714 | 35100 | 0.07953 | 238.198 | 183.59 | 6.0348 | 22.563 | 72.089 |
| DMK-16 | 3225 | 55.6025 | 791.463 | 0.0832 | 19492 | 0.05119 | 137.389 | 88.17 | 2.5608 | 6.481 | 69.765 |
| DMK-17 | 5706 | 92.1768 | 1170.556 | 0.06766 | 30559 | 0.0727 | 297.37 | 212.33 | 2.9652 | 13.617 | 82.295 |
| DMK-18 | 76891 | 98.897 | 3065.504 | 0.06562 | 63635 | 0.11517 | 872.518 | 150.57 | 10.1874 | 91.289 | 109.359 |
| DMK-20 | 8093 | 84.8584 | 1796.771 | 0.10074 | 35358 | 0.15849 | 319.981 | 129.71 | 6.5988 | 29.382 | 93.062 |
| GPM-01 | 5423 | 8.4175 | 10.122 | 0.50112 | 45689 | 1.11776 | 1304.832 | 204.77 | 1.5511 | 13.204 | 8.091 |
| GPM-02 | 24289 | 23.1947 | 26.854 | 0.35009 | 23633 | 17.94244 | 50.918 | 263.98 | 1.3009 | 37.809 | 9.167 |
| GPM-03 | 9627 | 24.8549 | 24.57 | 0.14107 | 19216 | 1.2355 | 36.125 | 218.12 | 0.4534 | 14.297 | 5.547 |
| GPM-04 | 3752 | 24.0747 | 10.587 | 0.12255 | 18928 | 0.22539 | 118.464 | 218.97 | 0.3317 | 6.994 | 4.621 |
| GPM-05 | 7668 | 19.366 | 14.075 | 0.28667 | 20726 | 4.46669 | 37.266 | 210.07 | 0.4143 | 11.93 | 7.647 |
| GPM-06 | 5999 | 15.6893 | 8.417 | 0.10437 | 17532 | 0.58996 | 29.731 | 192.49 | 0.3097 | 9.737 | 7.407 |
| GPM-07 | 8133 | 19.3785 | 13.304 | 0.25141 | 21316 | 4.34528 | 36.563 | 206.06 | 0.4585 | 14.519 | 4.98 |
| GPM-08 | 1498 | 18.5584 | 25.875 | 0.12068 | 29505 | 0.05865 | 54.423 | 285.49 | 0.0747 | 10.443 | 39.973 |
| GPM-09 | 4279 | 19.22 | 8.61 | 0.19906 | 36804 | 0.23435 | 147.245 | 360.61 | 1.1449 | 14.331 | 31.427 |
| GPM-10 | 5561 | 36.8421 | 25.899 | 0.16076 | 29597 | 0.45556 | 54.699 | 353.48 | 0.5022 | 7.632 | 7.623 |
| GPM-11 | 18993 | 14.8698 | 61.788 | 0.46786 | 26801 | 6.35172 | 56.388 | 205.27 | 0.9813 | 48.626 | 64.933 |
| GPM-12 | 7446 | 19.5151 | 12.835 | 0.33685 | 21322 | 4.06235 | 42.238 | 198.83 | 0.4171 | 10.7 | 42.227 |
| GPM-13 | 1781 | 8.3863 | 10.379 | 0.12722 | 19072 | 0.12013 | 51.999 | 205.65 | 0.9786 | 12.944 | 51.959 |
| GPM-14 | 1335 | 12.6894 | 4.039 | 0.10503 | 21446 | 0.05999 | 74.57 | 196.98 | 0.0397 | 9.987 | 216.002 |
| GPM-15 | 22140 | 28.7355 | 25.059 | 0.31456 | 24413 | 7.25684 | 123.649 | 197.34 | 1.1818 | 33.229 | 69.755 |
| GPM-16 | 10669 | 22.1336 | 15.308 | 0.2314 | 20895 | 6.09588 | 37.484 | 218.02 | 0.4693 | 14.147 | 35.495 |
| GPM-17 | 22519 | 8.5138 | 25.909 | 0.4299 | 27974 | 4.20658 | 69.799 | 186.57 | 2.2795 | 37.216 | 62.572 |
| GPM-18 | 14257 | 22.9619 | 25.549 | 0.31974 | 22123 | 11.46318 | 36.009 | 239.07 | 0.6139 | 18.512 | 38.234 |
| GPM-19 | 85546 | 45.6732 | 208.263 | 2.15307 | 61127 | 64.98015 | 226.23 | 283.9 | 6.8655 | 173.279 | 127.264 |
| GPM-20 | 10051 | 13.7382 | 17.975 | 0.36369 | 22320 | 1.32386 | 40.08 | 225.71 | 1.327 | 21.891 | 58.115 |
| JAMPT-01 | 1379 | 0.833 | 3.804 | 0.07126 | 9150 | 0.10014 | 12.848 | 189.04 | 0.0403 | 1.059 | 21.178 |
| JAMPT-02 | 1247 | 8.2883 | 6.595 | 0.07072 | 38615 | 0.17226 | 21.009 | 179.33 | 0.0356 | 1.283 | 132.905 |
| JAMPT-03 | 1499 | 0.5007 | 0.795 | 0.07731 | 14379 | 0.0715 | 34.591 | 234.9 | 0.0313 | 1.024 | 42.897 |
| JAMPT-04 | 1237 | 0.7343 | 0.741 | 0.08361 | 17375 | 0.05548 | 11.869 | 144.93 | 0.0236 | 0.879 | 37.654 |
| JAMPT-05 | 1008 | 0.6014 | 0.602 | 0.07076 | 15601 | 0.06094 | 9.419 | 162.48 | 0.011 | 0.736 | 30.932 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| JAMPT-06 | 1312 | 0.6122 | 1.141 | 0.06523 | 13932 | 0.04025 | 13.107 | 173.56 | 0.022 | 0.86 | 16.417 |
| JAMPT-07 | 1075 | 0.4282 | 0.624 | 0.07321 | 6567 | 0.05699 | 7.349 | 155.13 | 0.0219 | 0.841 | 19.32 |
| JAMPT-08 | 1156 | 0.4964 | 0.446 | 0.07473 | 14706 | 0.05947 | 8.836 | 165.15 | 0.0171 | 0.757 | 27.459 |
| JAMPT-09 | 1174 | 0.4168 | 0.68 | 0.06992 | 5232 | 0.08573 | 8.023 | 177.25 | 0.0346 | 0.657 | 26.997 |
| JAMPT-10 | 1334 | 0.3708 | 0.5 | 0.06937 | 9528 | 0.05464 | 6.995 | 180.79 | 0.0223 | 1.023 | 25.009 |
| JAMPT-11 | 1093 | 0.2597 | 1.882 | 0.08931 | 5597 | 0.04213 | 5.976 | 168.91 | 0.0272 | 0.705 | 15.003 |
| JAMPT-12 | 1144 | 0.2401 | 0.471 | 0.06716 | 7817 | 0.01537 | 6.731 | 183.36 | 0.0243 | 0.469 | 14.549 |
| JAMPT-13 | 1145 | 0.2698 | 1.544 | 0.06486 | 4570 | 0.02788 | 6.138 | 159.5 | 0.0247 | 0.975 | 15.477 |
| JAMPT-14 | 1136 | 0.2078 | 0.727 | 0.05722 | 9072 | 0.02466 | 7.328 | 164.36 | 0.0366 | 1.213 | 15.572 |
| JAMPT-15 | 1461 | 0.6933 | 0.537 | 0.06947 | 13019 | 0.03613 | 9.81 | 360.55 | 0.0188 | 0.794 | 18.599 |
| JAMPT-16 | 1117 | 0.2918 | 0.751 | 0.05119 | 4755 | 0.0436 | 6.677 | 197.6 | 0.0231 | 0.756 | 15.213 |
| JAMPT-17 | 1157 | 0.2158 | 0.522 | 0.07858 | 7256 | 0.0226 | 6.683 | 155.56 | 0.0196 | 0.806 | 13.54 |
| JAMPT-18 | 1309 | 0.5034 | 0.947 | 0.0683 | 15084 | 0.02816 | 10.079 | 207.54 | 0.0143 | 0.618 | 20.928 |
| JAMPT-19 | 1252 | 0.5468 | 1.002 | 0.06902 | 14749 | 0.02474 | 11.595 | 172.46 | 0.0159 | 0.775 | 20.737 |
| JAMPT-20 | 1261 | 0.5621 | 1.069 | 0.07926 | 10466 | 0.09022 | 77.548 | 199.55 | 0.0366 | 1.116 | 35.229 |
| JJC-01 | 6990 | 0.1853 | 0.33 | 0.04307 | 44 | 0.0534 | 154.999 | 322.91 | 0.0031 | 18.148 | 40.135 |
| JJC-02 | 9246 | 6.0981 | 4.845 | 0.08487 | 14310 | 0.11995 | 157.802 | 340.18 | 2.9137 | 21.823 | 33.726 |
| JJC-03 | 1758 | 0.2027 | 0.314 | 0.05447 | 47 | 0.06793 | 133.854 | 283.87 | 0.0035 | 3.316 | 48.914 |
| JJC-04 | 2243 | 0.2351 | 0.353 | 0.04411 | 33 | 0.05856 | 114.642 | 266.95 | 0.0041 | 4.651 | 43.524 |
| JJC-05 | 2623 | 0.3619 | 2.491 | 0.35008 | 54 | 0.49835 | 116.724 | 275.82 | 0.0149 | 6.455 | 22.291 |
| JJC-06 | 8952 | 0.3187 | 2.359 | 0.34139 | 70 | 0.50709 | 156.497 | 263.83 | 0.012 | 20.164 | 17.807 |
| JJC-07 | 2102 | 0.3348 | 2.89 | 0.38883 | 48 | 0.45103 | 109.128 | 269.15 | 0.0134 | 12.832 | 18.612 |
| JJC-08 | 5299 | 0.3794 | 2.419 | 0.35955 | 81 | 0.58381 | 137.744 | 252.38 | 0.0156 | 14.179 | 18.696 |
| JJC-09 | 6518 | 14.0348 | 19.601 | 0.45997 | 29285 | 121.5312 | 154.907 | 16319.96 | 2.3598 | 8.874 | 14.725 |
| JJC-10 | 13627 | 12.7119 | 55.899 | 0.50571 | 29840 | 15.606 | 189.93 | 12565.6 | 5.5855 | 34.026 | 15.437 |
| JJG-01 | 24526 | 3.9645 | 17.9 | 0.12391 | 15274 | 3.87767 | 87.915 | 232.67 | 2.9505 | 43.847 | 19.097 |
| JJG-02 | 31808 | 0.1741 | 0.386 | 0.04072 | 36 | 0.04949 | 103.295 | 197.85 | 0.0043 | 72.347 | 46.122 |
| JJG-03 | 19978 | 3.5207 | 12.767 | 0.14479 | 15193 | 1.51699 | 98.624 | 180.98 | 1.9723 | 43.19 | 30.886 |
| JJG-04 | 33843 | 9.5106 | 45.377 | 0.17243 | 35365 | 4.71019 | 107.383 | 131.62 | 8.027 | 72.892 | 47.839 |
| JJG-05 | 14324 | 7.2124 | 25.284 | 0.12033 | 30075 | 0.276 | 90.922 | 233.52 | 3.0565 | 28.216 | 68.592 |
| JJG-06 | 41385 | 8.3865 | 53.056 | 0.29927 | 44328 | 4.54264 | 132.624 | 263.58 | 7.4134 | 64.043 | 82.375 |
| JJG-07 | 29566 | 8.0928 | 38.079 | 0.22674 | 42270 | 3.84057 | 142.426 | 180.17 | 4.1784 | 53.333 | 76.196 |
| JJG-08 | 70593 | 8.5728 | 48.814 | 0.59401 | 58928 | 3.91057 | 207.489 | 146.86 | 15.8474 | 118.727 | 108.747 |
| JJG-09 | 31927 | 7.2202 | 11.035 | 0.09705 | 40467 | 0.16359 | 143.197 | 173.91 | 3.0742 | 40.962 | 88.855 |
| JJG-10 | 28399 | 8.1931 | 35.435 | 0.50814 | 39406 | 16.65383 | 118.204 | 241.17 | 4.7817 | 47.249 | 43.502 |
| JJK-01 | 3685 | 1.5753 | 1.563 | 0.05508 | 9231 | 0.04987 | 70.293 | 180.6 | 0.199 | 8.964 | 74.401 |
| JJK-02 | 9728 | 3.3094 | 15.843 | 0.06036 | 18837 | 0.32648 | 69.267 | 191.34 | 1.6718 | 62.173 | 25.558 |
| JJK-03 | 1541 | 0.2276 | 0.383 | 0.05303 | 30 | 0.04577 | 50.93 | 144.2 | 0.0053 | 5.093 | 6.201 |
| JJK-04 | 9180 | 3.222 | 21.099 | 0.1403 | 19488 | 0.22823 | 67.95 | 244.11 | 1.9481 | 74.254 | 57.605 |
| JJK-05 | 4954 | 2.1792 | 10.648 | 0.11419 | 15938 | 0.1372 | 44.129 | 224.29 | 0.6567 | 15.755 | 91.888 |
| JJK-06 | 4680 | 2.8266 | 8.905 | 0.08363 | 14772 | 0.07184 | 54.351 | 229.28 | 0.8224 | 11.835 | 89.123 |
| JJK-07 | 4302 | 4.1537 | 4.475 | 0.11697 | 20532 | 0.19185 | 59.809 | 263.57 | 0.369 | 5.968 | 266.065 |
| JJK-08 | 14232 | 4.292 | 30.599 | 0.1115 | 22809 | 0.20238 | 84.792 | 254.2 | 2.3877 | 105.191 | 61.789 |
| JJK-09 | 2227 | 3.8478 | 6.223 | 0.09316 | 20382 | 0.04504 | 50.226 | 217.11 | 0.2755 | 12.34 | 141.149 |
| JJK-10 | 8797 | 3.5129 | 14.861 | 0.09683 | 18827 | 0.17594 | 61.967 | 232.05 | 1.4878 | 76.901 | 86.732 |
| Kot(MP-1) | 2224 | 84.15 | 1370 | 0.3512 | 42290 | 0.4218 | 325.2 | 120.3 | 6.14 | 22.75 | 57.54 |
| Kot(MP-2) | 11890 | 89.55 | 1828 | 0.455 | 41910 | 0.06993 | 182.7 | 123.6 | 6.013 | 38.13 | 64.48 |
| Kot(MP-3) | 9966 | 85.24 | 1553 | 0.4414 | 42190 | 0.06743 | 210.2 | 95.51 | 5.297 | 31.26 | 60.18 |
| Kot(MP-4) | 1445 | 81.17 | 2616 | 0.4146 | 39760 | 0.06211 | 229 | 52.98 | 1.672 | 23.41 | 96.78 |
| KOT-01 | 10279 | 113.6252 | 4662.838 | 0.47283 | 71332 | 0.09096 | 1020.337 | 140.8 | 3.1707 | 262.556 | 30.659 |
| KOT-02 | 53791 | 83.8528 | 1244.02 | 0.51041 | 37434 | 0.08981 | 591.108 | 161.8 | 6.9744 | 88.666 | 15.921 |
| KOT-03 | 15370 | 80.674 | 2125.4 | 0.49256 | 42682 | 0.09401 | 209.666 | 156.7 | 6.6963 | 23.692 | 15.845 |
| KOT-04 | 62687 | 103.0556 | 2546.115 | 0.51432 | 43187 | 0.0898 | 885.357 | 169.11 | 3.5859 | 136.785 | 15.27 |
| KOT-05 | 7121 | 87.4994 | 1451.672 | 0.57215 | 35729 | 0.08799 | 750.593 | 167.94 | 3.6289 | 70.172 | 9.443 |
| KOT-06 | 4617 | 88.82 | 1602 | 1.297 | 35770 | 0.1033 | 115 | 100.5 | 2.477 | 14.81 | 41.18 |
| KOT-07 | 35610 | 94.41 | 3627 | 2.567 | 46870 | 0.05429 | 555.5 | 146.7 | 4.574 | 107 | 44.25 |
| KOT-08 | 7249 | 78.21 | 1341 | 2.519 | 42010 | 0.05985 | 374 | 191.8 | 6.299 | 66.71 | 33.18 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KOT-09 | 20820 | 83.82 | 1367 | 1.722 | 38630 | 0.07753 | 465.3 | 213.4 | 8.406 | 56.93 | 34.08 |
| KOT-10 | 20290 | 102.8 | 3201 | 0.4078 | 46990 | 0.05813 | 376 | 176.7 | 4.287 | 58.37 | 38.76 |
| KOT-11 | 21940 | 104.1 | 3291 | 0.3911 | 48490 | 0.0676 | 325.1 | 102.4 | 4.372 | 50.08 | 37.92 |
| KOT-12 | 19628 | 92.7521 | 2402.644 | 0.08404 | 47647 | 1.00427 | 375.772 | 127.32 | 14.3725 | 55.517 | 55.978 |
| KOT-13 | 16008 | 85.888 | 1802.188 | 0.07151 | 41634 | 0.87432 | 341.235 | 126.68 | 11.0025 | 43.475 | 51.601 |
| KOT-14 | 2568 | 89.6967 | 3299.438 | 0.05287 | 45061 | 0.63052 | 413.515 | 144.35 | 1.9482 | 43.783 | 150.44 |
| KOT-15 | 28960 | 106.6857 | 5386.251 | 0.06334 | 56553 | 0.83591 | 451.561 | 169.64 | 5.4215 | 98.399 | 77.618 |
| KOT-16 | 25264 | 102.4266 | 3539.983 | 0.05471 | 48325 | 0.80864 | 368.535 | 132.62 | 5.4055 | 55.365 | 52.277 |
| LBW1-01 | 10660 | 59.19 | 1864 | 0.08683 | 23610 | 0.5173 | 142.1 | 758 | 8.342 | 31.64 | 11.06 |
| LBW1-02 | 7436 | 41.91 | 1974 | 0.09187 | 16530 | 7.333 | 61.96 | 443.9 | 8.863 | 29.02 | 10.56 |
| LBW1-03 | 3059 | 46.61 | 777.6 | 0.05207 | 13680 | 0.02384 | 44.93 | 246.3 | 2.19 | 13.98 | 4.723 |
| LBW1-04 | 3034 | 43.8 | 843.2 | 0.04536 | 12080 | 6.337 | 28 | 369.3 | 2.328 | 10.58 | 7.056 |
| LBW1-05 | 2558 | 49.59 | 463.9 | 0.08829 | 16230 | 0.0439 | 38.18 | 371.7 | 3.071 | 6.412 | 10.93 |
| LBW1-06 | 3617 | 51.4 | 1042 | 0.1002 | 16170 | 0.05558 | 124.8 | 649 | 2.465 | 13.03 | 11.66 |
| LBW1-07 | 3749 | 6.491 | 248.6 | 0.03634 | 1910 | 0.02159 | 65.07 | 158.8 | 1.106 | 13.02 | 5.711 |
| LBW1-08 | 3958 | 27.07 | 1292 | 0.1028 | 9074 | 0.07589 | 72.03 | 626.5 | 4.915 | 17 | 11.2 |
| LBW1-09 | 3501 | 43.13 | 1055 | 0.08619 | 13170 | 0.02603 | 24.79 | 400.8 | 3.098 | 12.94 | 10.42 |
| LBW1-10 | 3248 | 26.25 | 708.6 | 0.09374 | 8610 | 0.05953 | 68.74 | 664.4 | 3.638 | 11.05 | 10.47 |
| LBW2-01 | 1232 | 31.4654 | 6.137 | 0.03603 | 10011 | 0.12838 | 22.476 | 447.95 | 0.3155 | 1.706 | 7.006 |
| LBW2-02 | 11688 | 56.1296 | 3863.705 | 0.10088 | 17940 | 0.33392 | 55.316 | 1604.29 | 15.9825 | 55.378 | 15.986 |
| LBW2-03 | 1372 | 36.3546 | 9.285 | 0.03629 | 9804 | 0.12717 | 20.708 | 618.21 | 0.2633 | 1.176 | 5.357 |
| LBW2-04 | 1660 | 53.0697 | 111.371 | 0.04283 | 15897 | 0.16725 | 34.424 | 755.26 | 0.5807 | 2.231 | 8.672 |
| LBW2-05 | 2100 | 87.9788 | 405.484 | 0.06212 | 22286 | 0.23746 | 39.51 | 1308.92 | 1.85 | 4.668 | 12.607 |
| LBW2-06 | 1906 | 46.2385 | 11.993 | 0.05484 | 12980 | 0.15548 | 18.246 | 919.94 | 0.5179 | 4.225 | 9.03 |
| LBW2-07 | 3731 | 75.4578 | 1644.424 | 0.0724 | 19356 | 0.25201 | 44.295 | 1757.21 | 3.8246 | 16.088 | 13.461 |
| LBW2-08 | 3471 | 77.0846 | 1020.591 | 0.07091 | 19851 | 0.26522 | 50.84 | 1574.25 | 3.0339 | 10.61 | 12.883 |
| LBW2-09 | 2455 | 54.9975 | 1735.822 | 0.06796 | 16819 | 0.2671 | 38.334 | 1689.31 | 5.1673 | 11.811 | 13.381 |
| LBW2-10 | 3616 | 81.0977 | 582.736 | 0.06905 | 22328 | 0.29036 | 52.205 | 1882.59 | 4.7158 | 13.003 | 14.7 |
| LKPD-01 | 2051 | 0.3951 | 0.788 | 0.05787 | 1660 | 0.16213 | 95.797 | 174.46 | 0.0326 | 1.381 | 184.104 |
| LKPD-02 | 1538 | 2.3073 | 0.875 | 0.05326 | 8403 | 0.1397 | 84.793 | 199.83 | 0.0774 | 1.958 | 422.641 |
| LKPD-03 | 2109 | 3.1554 | 1.525 | 0.05194 | 7896 | 0.14352 | 25.502 | 338.9 | 0.2482 | 6.269 | 190.661 |
| LKPD-04 | 1921 | 2.2941 | 1.296 | 0.06186 | 8433 | 0.14596 | 85.461 | 190.35 | 0.0845 | 2.609 | 402.98 |
| LKPD-05 | 4285 | 1.5973 | 2.489 | 0.05774 | 6349 | 0.17328 | 31.139 | 336.65 | 0.4567 | 11.052 | 164.716 |
| LKPD-06 | 2322 | 0.4071 | 1.309 | 0.05971 | 1677 | 0.14938 | 61.943 | 191.1 | 0.0344 | 2.407 | 186.883 |
| LKPD-07 | 2034 | 0.37 | 0.963 | 0.05757 | 3071 | 0.1666 | 23.069 | 438.97 | 0.3495 | 4.941 | 148.966 |
| LKPD-08 | 35547 | 0.6907 | 1.348 | 0.05251 | 3874 | 0.28324 | 156.189 | 188.66 | 1.8086 | 7.207 | 131.423 |
| LKPD-09 | 54080 | 0.5053 | 5.901 | 0.29823 | 4981 | 3.03927 | 216.854 | 179.41 | 1.3464 | 11.733 | 156.365 |
| LKPD-10 | 47133 | 0.703 | 1.1 | 0.13176 | 4669 | 7.01164 | 201.454 | 161.14 | 3.1181 | 8.916 | 94.654 |
| LKPD-11 | 2200 | 0.2177 | 0.591 | 0.46942 | 2570 | 0.04167 | 103.658 | 165.17 | 0.0346 | 1.252 | 40.244 |
| LKPD-12 | 74984 | 0.5204 | 0.88 | 0.48371 | 4534 | 1.28103 | 327.576 | 177.24 | 2.6154 | 12.668 | 26.948 |
| LKPD-13 | 10140 | 0.2617 | 0.744 | 0.45007 | 3787 | 0.0258 | 89.243 | 402.87 | 0.373 | 24.489 | 20.984 |
| LKPD-14 | 8210 | 2.4173 | 0.557 | 0.45439 | 8814 | 0.03559 | 119.224 | 428.89 | 0.7501 | 17.36 | 18.662 |
| LKPD-15 | 99602 | 0.4038 | 0.808 | 0.49246 | 3303 | 0.09141 | 446.06 | 223.34 | 1.4668 | 21.341 | 22.068 |
| LKPD-16 | 3747 | 0.9298 | 7.391 | 0.3593 | 5010 | 0.1431 | 30.83 | 328.2 | 0.3951 | 11.82 | 148.7 |
| LKPD-17 | 4805 | 1.139 | 7.493 | 1.434 | 5172 | 0.1837 | 29.39 | 321.7 | 0.4798 | 14.56 | 148.7 |
| LKPD-18 | 2207 | 1.322 | 7.598 | 0.9421 | 6460 | 0.2588 | 10.47 | 116.4 | 0.7434 | 5.121 | 146.7 |
| LKPD-19 | 7085 | 1.477 | 6.421 | 1.014 | 6741 | 0.2308 | 33.94 | 312.2 | 0.7042 | 20.43 | 138.3 |
| LKPD-20 | 2208 | 0.4501 | 1.753 | 0.9406 | 1471 | 0.04287 | 47.36 | 178.9 | 0.0372 | 1.85 | 130.4 |
| PD-01 | 1708 | 2.0044 | 0.791 | 0.05249 | 1470 | 0.25221 | 1.576 | 192.06 | 0.0715 | 1.907 | 31.22 |
| PD-02 | 1762 | 24.0847 | 1.267 | 0.06126 | 27885 | 0.32545 | 77.307 | 212.95 | 0.15 | 2.364 | 190.765 |
| PD-03 | 1687 | 0.8221 | 0.585 | 0.0515 | 770 | 0.35255 | 2.133 | 212.97 | 0.0471 | 1.205 | 15.468 |
| PD-04 | 1719 | 2.5871 | 1.762 | 0.06186 | 4086 | 1.71931 | 5.96 | 177.04 | 0.0323 | 1.834 | 33.842 |
| PD-05 | 1649 | 1.2068 | 0.707 | 0.05036 | 1121 | 0.26823 | 5.567 | 179.2 | 0.019 | 1.339 | 49.572 |
| PD-06 | 2011 | 1.547 | 0.969 | 0.05174 | 1938 | 0.2444 | 4.627 | 243.83 | 0.0414 | 3.216 | 29.786 |
| PD-07 | 1785 | 1.6196 | 0.873 | 0.05185 | 1427 | 1.10195 | 2.256 | 304.84 | 0.0305 | 2.678 | 9.692 |
| PD-08 | 1755 | 1.0971 | 0.758 | 0.03522 | 678 | 0.05414 | 2.098 | 193.62 | 0.0371 | 1.676 | 9.562 |
| PD-09 | 1687 | 2.2671 | 0.723 | 0.02724 | 1478 | 0.13537 | 2.251 | 333.59 | 0.0601 | 1.727 | 8.395 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PD-10 | 1634 | 1.9469 | 1.07 | 0.02631 | 4469 | 0.09727 | 2.385 | 347.6 | 0.1025 | 1.891 | 8.301 |
| PD-11 | 1901 | 13.3491 | 1.884 | 0.04549 | 9939 | 0.02515 | 6.556 | 213.79 | 0.0895 | 4.86 | 43.288 |
| PD-12 | 1838 | 6.3418 | 1.454 | 0.05649 | 3572 | 0.03023 | 3.386 | 226.66 | 0.0253 | 1.474 | 16.003 |
| PD-13 | 3385 | 2.1819 | 1.731 | 0.04645 | 1423 | 1.38453 | 7.321 | 229.33 | 0.0929 | 3.427 | 51.006 |
| PD-14 | 1531 | 1.6763 | 1.514 | 0.05012 | 3215 | 0.02343 | 3.549 | 232.32 | 0.0517 | 1.565 | 60.547 |
| PD-15 | 1669 | 0.8269 | 0.877 | 0.05848 | 711 | 0.08888 | 1.124 | 244.46 | 0.0555 | 1.626 | 36.693 |
| PD-16 | 1636 | 0.6701 | 1.327 | 0.0456 | 599 | 0.01505 | 1.573 | 233.02 | 0.0305 | 2.092 | 33.997 |
| PD-17 | 1864 | 6.6076 | 1.66 | 0.05783 | 3730 | 0.02943 | 3.135 | 253.33 | 0.0205 | 1.41 | 69.406 |
| PD-18 | 1443 | 1.0907 | 1.7 | 0.04861 | 817 | 0.23827 | 1.36 | 210.08 | 0.018 | 1.232 | 54.408 |
| PD-19 | 1586 | 1.508 | 1.059 | 0.0457 | 3323 | 0.04488 | 2.753 | 163.88 | 0.0444 | 1.556 | 63.227 |
| PD-20 | 1675 | 1.4727 | 1.505 | 0.04203 | 2525 | 0.0915 | 2.43 | 178.06 | 0.0498 | 2.348 | 67.608 |
| RDP-01 | 5271 | 4.3582 | 6.633 | 0.08545 | 9816 | 0.07692 | 38.649 | 190.92 | 0.5778 | 8.007 | 32.223 |
| RDP-02 | 4017 | 5.3453 | 11.976 | 0.21093 | 9244 | 0.97501 | 139.822 | 174.22 | 0.9065 | 7.178 | 36.126 |
| RDP-03 | 1827 | 2.1209 | 1.287 | 0.12915 | 8172 | 0.37762 | 49.829 | 136.72 | 0.4865 | 4.354 | 27.368 |
| RDP-04 | 2222 | 3.7109 | 2.236 | 0.09766 | 9009 | 0.29137 | 31.201 | 175.5 | 0.3351 | 5.978 | 34.155 |
| RDP-05 | 16128 | 3.6427 | 24.507 | 0.28277 | 9790 | 11.34843 | 28.445 | 210.79 | 2.4715 | 29.819 | 29.303 |
| RDP-06 | 25674 | 5.1891 | 19.756 | 0.16445 | 13951 | 0.89244 | 96.172 | 144.96 | 3.6496 | 38.567 | 34.924 |
| RDP-07 | 6060 | 7.022 | 8.102 | 0.18126 | 12505 | 0.72266 | 199.698 | 282.53 | 1.4424 | 10.709 | 27.21 |
| RDP-08 | 2194 | 3.1073 | 4.06 | 0.06276 | 7655 | 0.19639 | 21.792 | 155.31 | 0.4748 | 4.235 | 32.6 |
| RDP-09 | 3993 | 3.6526 | 5.685 | 0.10229 | 9492 | 0.666 | 29.303 | 141.79 | 0.8559 | 5.87 | 25.754 |
| RDP-10 | 5393 | 2.6156 | 7.629 | 0.28016 | 8265 | 6.02314 | 30.581 | 170.28 | 0.7634 | 8.998 | 15.855 |
| RDP-11 | 14130 | 1.001 | 1.932 | 0.6374 | 2349 | 6.835 | 93.57 | 409 | 4.714 | 68.05 | 31.07 |
| RDP-12 | 5914 | 1.066 | 1.259 | 0.5266 | 2030 | 1.016 | 47.38 | 494.9 | 1.764 | 32.72 | 27.36 |
| RDV-01 | 1276 | 2.4106 | 2.889 | 0.06526 | 5421 | 4.19301 | 17.907 | 171.61 | 0.0174 | 0.728 | 252.903 |
| RDV-03 | 1429 | 1.815 | 1.44 | 0.08685 | 9155 | 6.20208 | 29.915 | 211.25 | 0.0123 | 1.3 | 265.764 |
| RDV-04 | 1185 | 4.7467 | 12.954 | 0.08755 | 7060 | 6.30798 | 161.048 | 191.87 | 0.0154 | 1.476 | 226.255 |
| RDV-05 | 1702 | 2.0008 | 1.913 | 0.10625 | 4599 | 5.85611 | 17.732 | 288.6 | 0.0104 | 2.885 | 242.49 |
| RDV-06 | 1713 | 1.9793 | 1.656 | 0.07648 | 4845 | 5.32474 | 16.932 | 264.39 | 0.0155 | 1.455 | 210.027 |
| RDV-07 | 1770 | 2.1028 | 2.56 | 0.10252 | 4540 | 6.25825 | 14.528 | 255.05 | 0.0128 | 2.049 | 252.823 |
| RDV-08 | 2051 | 2.6776 | 5.734 | 0.08093 | 7739 | 7.94283 | 18.702 | 269.81 | 0.0722 | 2.893 | 286.477 |
| RDV-09 | 1439 | 3.0189 | 2.445 | 0.06672 | 7703 | 7.14964 | 31.822 | 204.4 | 0.0224 | 1.031 | 280.178 |
| RDV-10 | 2092 | 2.5326 | 6.563 | 0.11189 | 7603 | 12.04493 | 21.418 | 247.51 | 0.0537 | 3.022 | 268.293 |
| RKA-01 | 36172 | 23.83 | 50.719 | 0.16931 | 33503 | 1.50299 | 200.752 | 463.67 | 11.7137 | 87.37 | 48.14 |
| RKA-02 | 91679 | 25.2074 | 156.835 | 0.45671 | 45416 | 8.79662 | 191.203 | 243.28 | 24.5474 | 178.612 | 61.182 |
| RKA-03 | 34650 | 23.9842 | 73.438 | 0.2052 | 29006 | 1.30315 | 93.675 | 398.14 | 10.5958 | 72.636 | 43.974 |
| RKA-04 | 50546 | 23.9374 | 114.613 | 0.30406 | 38445 | 6.18829 | 167.121 | 230.42 | 16.5218 | 100.02 | 53.707 |
| RKA-05 | 31487 | 23.902 | 70.71 | 0.41156 | 27138 | 11.61102 | 106.731 | 472.39 | 9.8072 | 71.977 | 12.736 |
| RKA-06 | 41174 | 24.4836 | 83.459 | 0.11351 | 32260 | 2.05011 | 107.38 | 460.43 | 12.9429 | 81.43 | 13.144 |
| RKA-07 | 56076 | 24.6131 | 144.295 | 0.2681 | 40377 | 8.75675 | 173.149 | 368.64 | 17.8488 | 110.471 | 15.011 |
| RKA-08 | 58897 | 28.6735 | 103.171 | 0.23479 | 41109 | 4.81383 | 130.934 | 394.48 | 15.5174 | 98.947 | 14.308 |
| RKA-09 | 8412 | 16.9576 | 61.345 | 0.9113 | 11031 | 28.87787 | 32.796 | 496.9 | 3.1146 | 28.916 | 11.431 |
| RKA-10 | 50454 | 24.9277 | 101.51 | 0.25482 | 37012 | 7.75869 | 160.896 | 419.23 | 15.1434 | 110.402 | 14.195 |
| RKA-11 | 53340 | 54.19 | 29.97 | 0.4953 | 47750 | 0.5519 | 79.43 | 186 | 15.01 | 123.2 | 51.65 |
| RKA-12 | 184400 | 0.5864 | 35.26 | 2.415 | 744 | 29.34 | 7.861 | 7881 | 31.44 | 144 | 46.86 |
| RKA-13 | 41710 | 39.21 | 2.555 | 1.889 | 46280 | 1.674 | 60.43 | 65.5 | 20.13 | 66.25 | 40.54 |
| RKA-14 | 34190 | 65.27 | 125.1 | 2.623 | 46150 | 10.88 | 72.37 | 121.9 | 15.63 | 96.07 | 38.12 |
| RKA-15 | 79640 | 28.44 | 4.366 | 0.5778 | 29210 | 1.206 | 120.7 | 310.8 | 12.71 | 123.8 | 72.2 |
| RKA-16 | 70870 | 30.31 | 5.881 | 1.424 | 31840 | 27.91 | 101.6 | 291.5 | 12.25 | 104.3 | 76.12 |
| RKA-17 | 72770 | 53.54 | 67.71 | 0.4946 | 44240 | 3.493 | 103.8 | 299.6 | 14.64 | 181.8 | 84.91 |
| RKA-18 | 67490 | 52.78 | 62.47 | 1.636 | 45120 | 1.075 | 108.1 | 251.7 | 14.21 | 161.7 | 38.92 |
| RKA-19 | 172100 | 0.6079 | 31.54 | 0.5417 | 962 | 32.71 | 8.845 | 7923 | 30.91 | 117.3 | 64.66 |
| RKA-20 | 220300 | 39.52 | 4.618 | 0.691 | 42080 | 0.3581 | 283.8 | 228.6 | 15.68 | 343.1 | 50.73 |
| RKG-01 | 6740 | 109.2 | 2033 | 0.08467 | 50120 | 0.5585 | 220 | 132.9 | 6.802 | 28.66 | 89.53 |
| RKG-02 | 4630 | 93.52 | 6092 | 0.08067 | 66190 | 0.5236 | 577.3 | 217 | 3.383 | 42.26 | 182.2 |
| RKG-03 | 1076 | 81.86 | 20.62 | 0.05123 | 13750 | 0.3278 | 100.7 | 123 | 0.162 | 0.911 | 104.1 |
| RKG-04 | 3206 | 86.5 | 509.5 | 0.06472 | 24670 | 0.3737 | 240.4 | 216.5 | 1.497 | 5.731 | 195.6 |
| RKG-05 | 4855 | 97.44 | 5259 | 0.07609 | 47980 | 0.5145 | 693.3 | 188.4 | 3.174 | 35.09 | 690.4 |
| RKG-06 | 6467 | 88.6 | 478.6 | 0.06296 | 13770 | 0.4438 | 102.9 | 189.7 | 3.034 | 5.919 | 53.51 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RKG-07 | 8234 | 80.42 | 1072 | 0.06796 | 18100 | 0.4962 | 154.9 | 152.3 | 4.837 | 5.722 | 41.72 |
| RKG-08 | 2951 | 85.83 | 51.22 | 0.05545 | 13900 | 0.4317 | 99.46 | 172.5 | 1.79 | 3.492 | 34.3 |
| RKG-09 | 2240 | 76.79 | 180.3 | 0.04474 | 13700 | 0.3831 | 136.2 | 240 | 0.7921 | 1.311 | 71.97 |
| RKG-10 | 2337 | 71.64 | 186.6 | 0.04882 | 15490 | 0.4018 | 130.5 | 140.7 | 0.8817 | 2.454 | 75.01 |
| RMP-01 | 95930 | 140.9543 | 3120.007 | 0.13284 | 61589 | 0.07326 | 299.7 | 176.44 | 25.1114 | 89.29 | 110.933 |
| RMP-02 | 5609 | 93.8105 | 334.921 | 0.06213 | 25243 | 0.03468 | 96.6 | 172.02 | 2.6496 | 5.836 | 173.674 |
| RMP-03 | 1159 | 84.4118 | 36.212 | 0.05137 | 12809 | 0.02912 | 30.09 | 167.39 | 0.1221 | 1.012 | 397.125 |
| RMP-04 | 1306 | 92.9248 | 179.179 | 0.06767 | 32388 | 0.03678 | 42.37 | 164.56 | 0.2388 | 2.979 | 352.102 |
| RMP-05 | 1548 | 70.7914 | 23.901 | 0.07887 | 18185 | 0.03158 | 69.47 | 147.12 | 0.4034 | 1.966 | 301.214 |
| RMP-06 | 12800 | 86.0983 | 1575.066 | 0.06071 | 30355 | 0.04108 | 82.42 | 163.01 | 3.3739 | 16.09 | 161.729 |
| RMP-07 | 6784 | 76.8377 | 1349.078 | 0.05603 | 32551 | 0.04453 | 82.93 | 157.85 | 5.1664 | 18.31 | 84.601 |
| RMP-08 | 1556 | 99.1805 | 324.494 | 0.06336 | 24466 | 0.03499 | 45.52 | 158.41 | 0.406 | 6.668 | 348.01 |
| RMP-09 | 3636 | 93.0251 | 309.342 | 0.05786 | 24417 | 0.04311 | 416.754 | 158.9 | 2.8966 | 4.976 | 118.074 |
| RMP-10 | 102417 | 137.4092 | 321.927 | 0.10759 | 60126 | 0.08274 | 497.692 | 169.43 | 19.6657 | 100.077 | 231.025 |
| RRA-01 | 3308 | 3.1163 | 7.46 | 0.0618 | 2521 | 7.98333 | 6.077 | 137.63 | 0.1325 | 6.214 | 82.884 |
| RRA-02 | 4687 | 3.3231 | 10.984 | 0.09033 | 2574 | 11.61522 | 41.167 | 156.31 | 0.7305 | 9.587 | 48.053 |
| RRA-03 | 2382 | 2.0251 | 22.369 | 0.09453 | 2890 | 10.63241 | 7.645 | 205.73 | 0.7376 | 11.197 | 48.425 |
| RRA-04 | 1349 | 2.2966 | 1.538 | 0.07258 | 1314 | 7.70511 | 2.72 | 129.56 | 0.0158 | 3.05 | 87.835 |
| RRA-05 | 3513 | 51.623 | 321.92 | 0.06383 | 24467 | 9.7252 | 40.133 | 139.62 | 0.9675 | 5.791 | 98.802 |
| RRA-06 | 7531 | 61.6732 | 1556.495 | 0.05523 | 31276 | 13.81008 | 98.632 | 98.34 | 3.7643 | 16.61 | 42.225 |
| RRA-07 | 2781 | 3.2286 | 4.685 | 0.07349 | 9525 | 5.25564 | 25.934 | 310.8 | 0.0952 | 2.642 | 306.807 |
| RRA-08 | 7287 | 58.1925 | 851.218 | 0.06945 | 25694 | 13.65727 | 50.964 | 165.79 | 3.7636 | 13.189 | 38.802 |
| RRA-09 | 2082 | 2.9701 | 8.525 | 0.07206 | 2246 | 4.15094 | 8.014 | 157.1 | 0.1576 | 5.243 | 72.619 |
| RRA-10 | 1429 | 2.8026 | 1.376 | 0.05494 | 1651 | 4.33986 | 4.391 | 135.53 | 0.0244 | 3.043 | 93.597 |
| RRD-01 | 1959 | 83.5705 | 468.532 | 0.05942 | 23530 | 0.21717 | 94.923 | 1472.26 | 0.8505 | 2.716 | 49.058 |
| RRD-02 | 1348 | 70.2287 | 34.474 | 0.05255 | 18239 | 0.20317 | 166.615 | 1541.41 | 0.3647 | 1.351 | 36.55 |
| RSA-01 | 1297 | 3.6641 | 1.631 | 0.05424 | 15934 | 5.11319 | 64.912 | 195.12 | 0.0136 | 1.301 | 246.869 |
| RSA-02 | 1320 | 5.1421 | 1.383 | 0.06165 | 13638 | 6.36928 | 22.37 | 120.57 | 0.0118 | 2.38 | 89.875 |
| RSA-03 | 1214 | 6.0493 | 1.43 | 0.09701 | 16179 | 0.04524 | 21.12 | 165.31 | 0.0098 | 1.577 | 80.478 |
| RSA-04 | 1137 | 6.4652 | 2.669 | 0.05618 | 15802 | 0.06352 | 17.49 | 162.24 | 0.018 | 1.814 | 68.272 |
| RSA-05 | 1179 | 5.796 | 1.1 | 0.06665 | 13160 | 0.03395 | 21.52 | 164.18 | 0.0107 | 1.635 | 94.933 |
| RSA-06 | 1111 | 7.2579 | 2.135 | 0.06912 | 16361 | 0.07084 | 21.25 | 169.79 | 0.0137 | 1.779 | 97.477 |
| RSA-07 | 619 | 3.6217 | 2.628 | 0.15386 | 12578 | 0.67927 | 390.2 | 137.55 | 0.0726 | 2.3 | 56.689 |
| RSA-08 | 1313 | 5.1216 | 1.245 | 0.05699 | 14005 | 0.01753 | 22.74 | 179.86 | 0.0142 | 2.641 | 98.067 |
| RSA-09 | 1396 | 4.4707 | 1.96 | 0.06763 | 18552 | 0.08618 | 37.54 | 238.48 | 0.0184 | 1.404 | 150.88 |
| RSA-10 | 835 | 4.2234 | 2.743 | 0.13425 | 12130 | 0.50953 | 272.8 | 150.6 | 0.0553 | 1.994 | 94.474 |
| RSA-11 | 4224 | 5.481 | 0.832 | 0.4715 | 14760 | 0.1645 | 65.41 | 427.3 | 0.0548 | 12.79 | 81.72 |
| RSA-12 | 1909 | 1.646 | 2.129 | 0.8867 | 4381 | 0.0237 | 15.01 | 257.4 | 0.0252 | 1.895 | 201 |
| RSA-13 | 6204 | 0.8008 | 0.476 | 0.4404 | 1967 | 0.02182 | 23.69 | 472.2 | 0.0515 | 10.51 | 66.55 |
| RSA-14 | 2758 | 0.9182 | 0.841 | 0.4617 | 1610 | 0.02737 | 10.18 | 131.1 | 0.0404 | 5.05 | 29.67 |
| RSB-01 | 3842 | 88.98 | 1013 | 0.08024 | 31280 | 0.9057 | 313.3 | 146.3 | 2.786 | 10.56 | 30.9 |
| RSB-02 | 5575 | 92.45 | 2055 | 0.09512 | 47530 | 0.09053 | 918.2 | 161.3 | 6.275 | 25.71 | 12.16 |
| RSB-03 | 5010 | 88.05 | 978 | 0.06875 | 31170 | 0.1414 | 295.1 | 134.2 | 4.022 | 13.75 | 10.93 |
| RSB-04 | 16990 | 85.51 | 2208 | 0.08434 | 37780 | 0.453 | 520.8 | 136.3 | 9.399 | 23.11 | 12.52 |
| RSB-05 | 5190 | 91.71 | 1698 | 0.06604 | 36250 | 0.02811 | 332.4 | 141.4 | 3.136 | 22.69 | 27.19 |
| RSB-06 | 5191 | 89.22 | 1779 | 0.06471 | 34040 | 0.03105 | 331.7 | 138.4 | 3.053 | 21.13 | 23.67 |
| RSB-07 | 6175 | 98.21 | 1697 | 0.09682 | 40680 | 0.03449 | 1172 | 160.9 | 6.43 | 19.27 | 16.94 |
| RSH-01 | 1810 | 93.02 | 263.6 | 0.07499 | 22140 | 0.02323 | 253.6 | 186.3 | 1.546 | 4.055 | 29.56 |
| RSH-02 | 5376 | 76.61 | 46.75 | 0.0814 | 14070 | 0.02304 | 117.8 | 161.4 | 5.152 | 8.225 | 11.39 |
| RSH-03 | 4720 | 76.13 | 47.18 | 0.08208 | 13750 | 0.02431 | 101.9 | 163.2 | 5.055 | 7.079 | 9.588 |
| RSH-04 | 1755 | 96.95 | 456.4 | 0.08034 | 28640 | 0.02116 | 268 | 177.6 | 1.331 | 9.136 | 30.8 |
| RSH-05 | 1730 | 97.15 | 388 | 0.07673 | 28000 | 0.02098 | 248.7 | 181.7 | 1.558 | 7.915 | 26.19 |
| RST-02 | 996 | 70.2683 | 41.3 | 0.08989 | 17621 | 9.29932 | 46.893 | 107.45 | 0.178 | 0.634 | 124.05 |
| RST-03 | 10017 | 70.404 | 1434.462 | 0.09214 | 27893 | 32.16222 | 98.268 | 101.36 | 5.1225 | 20.524 | 44.897 |
| RST-04 | 1176 | 71.9147 | 15.751 | 0.06928 | 14639 | 20.5445 | 54.799 | 164.44 | 0.0815 | 0.974 | 143.533 |
| RST-05 | 1139 | 73.5815 | 37.453 | 0.07457 | 12412 | 21.21967 | 22.748 | 119.42 | 0.2337 | 0.827 | 83.93 |
| RST-06 | 1757 | 73.7518 | 170.759 | 0.06494 | 21493 | 22.92109 | 29.325 | 122.4 | 0.7184 | 2.157 | 64.934 |
| RST-07 | 1135 | 74.3835 | 19.241 | 0.08463 | 13982 | 22.65678 | 68.949 | 137.4 | 0.092 | 1.007 | 146.543 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RST-08 | 6471 | 58.6065 | 863.937 | 0.09531 | 30108 | 30.80349 | 99.724 | 104.4 | 4.7977 | 12.239 | 42.486 |
| RST-09 | 1127 | 72.6273 | 24.131 | 0.06839 | 12781 | 10.17662 | 48.925 | 162.17 | 0.0634 | 0.908 | 114.055 |
| RST-10 | 7889 | 86.8858 | 1217.922 | 0.06623 | 18104 | 16.40526 | 19.418 | 96.35 | 6.2831 | 14.163 | 29.159 |
| SB-01 | 13164 | 1.0651 | 4.558 | 0.09999 | 3967 | 0.22757 | 9.365 | 251.51 | 0.2577 | 9.379 | 38.473 |
| SB-02 | 541 | 1.0158 | 0.966 | 0.22407 | 1995 | 0.06909 | 1.863 | 353.81 | 0.3421 | 1.143 | 25.852 |
| SB-03 | 917 | 1.4161 | 1.289 | 0.19728 | 3602 | 0.11686 | 1.737 | 273.45 | 0.1769 | 2.456 | 32.784 |
| SB-04 | 1970 | 1.1915 | 0.759 | 0.19231 | 2929 | 0.02745 | 7.11 | 255.39 | 0.1066 | 2.528 | 34.394 |
| SB-05 | 1581 | 2.9249 | 3.338 | 0.23264 | 5573 | 1.17349 | 0.949 | 172.69 | 0.1836 | 3.965 | 31.463 |
| SB-06 | 1773 | 0.9407 | 0.692 | 0.08388 | 2856 | 0.07853 | 6.754 | 247.38 | 0.1556 | 3.369 | 57.218 |
| SB-07 | 21308 | 1.0883 | 15.135 | 0.15438 | 4606 | 0.33459 | 11.774 | 294.8 | 0.4185 | 13.66 | 53.352 |
| SB-08 | 2245 | 1.9204 | 1.482 | 0.07875 | 2719 | 1.31363 | 7.922 | 208.9 | 0.1512 | 5.996 | 36.161 |
| SB-09 | 9219 | 1.595 | 4.05 | 0.09071 | 3672 | 2.2706 | 7.379 | 175.63 | 0.2255 | 6.973 | 48.052 |
| SB-10 | 3043 | 1.7456 | 1.952 | 0.07052 | 2823 | 2.14967 | 13.311 | 160.48 | 0.1906 | 4.272 | 45.149 |
| SC-01 | 1681 | 0.9669 | 2.308 | 0.25428 | 2338 | 0.44635 | 2.799 | 248.97 | 0.9594 | 4.004 | 26.098 |
| SC-02 | 472 | 1.3294 | 2.696 | 0.6222 | 3118 | 58.19955 | 3.048 | 241.38 | 0.7902 | 1.801 | 23.082 |
| SC-03 | 2205 | 0.9621 | 1.235 | 0.22107 | 2850 | 0.07625 | 15.716 | 242.39 | 0.1877 | 3.922 | 35.439 |
| SC-04 | 2787 | 1.3421 | 5.309 | 0.30503 | 3925 | 2.41489 | 1.917 | 320.67 | 1.3106 | 3.708 | 23.514 |
| SC-05 | 1880 | 2.0954 | 1.352 | 0.09015 | 6047 | 0.08207 | 45.448 | 277.36 | 0.1517 | 1.964 | 39.57 |
| SC-06 | 13974 | 1.2766 | 8.474 | 0.16673 | 4250 | 5.01052 | 9.134 | 394.45 | 1.401 | 18.719 | 53.125 |
| SC-07 | 46462 | 1.5069 | 28.55 | 0.24325 | 7206 | 12.29991 | 17.947 | 256.16 | 2.0544 | 37.647 | 38.148 |
| SC-08 | 1596 | 1.7055 | 0.912 | 0.24535 | 2715 | 0.03291 | 8.034 | 259.64 | 0.1601 | 1.802 | 13.489 |
| SC-09 | 44776 | 1.5764 | 25.995 | 0.4053 | 6741 | 11.59144 | 19.667 | 251.75 | 1.9938 | 41.231 | 17.787 |
| SC-10 | 1545 | 3.216 | 2.164 | 0.08887 | 2255 | 2.57413 | 5.231 | 141.56 | 0.7177 | 5.415 | 18.987 |
| SKK-02 | 2298 | 1.1315 | 1.423 | 0.18733 | 2650 | 1.87836 | 3.025 | 240.59 | 0.1163 | 1.695 | 42.527 |
| SKK-03 | 4994 | 2.7071 | 4.523 | 0.08432 | 2609 | 2.29653 | 4.396 | 256 | 0.2136 | 9.593 | 41.467 |
| SKK-04 | 3407 | 1.1562 | 3.553 | 0.08582 | 3202 | 2.32511 | 6.534 | 288.87 | 0.2235 | 7.184 | 39.147 |
| SKK-05 | 1715 | 1.0525 | 2.131 | 0.19509 | 2982 | 0.11037 | 4.123 | 342.78 | 0.1924 | 3.108 | 43.932 |
| SKK-06 | 604 | 1.024 | 0.991 | 0.26006 | 2259 | 1.86413 | 1.152 | 3080.09 | 0.1092 | 0.55 | 80.241 |
| SKK-07 | 6687 | 1.021 | 1.258 | 0.47719 | 2377 | 1.5094 | 13.73 | 226.92 | 0.1036 | 2.902 | 5.687 |
| SKK-08 | 1985 | 1.1378 | 1.154 | 1.24236 | 2393 | 1.67625 | 3.953 | 255.42 | 0.1203 | 2.434 | 34.678 |
| SKK-09 | 1823 | 0.9898 | 1.18 | 0.0788 | 2377 | 2.76853 | 5.08 | 266.46 | 0.1091 | 1.519 | 47.38 |
| SKK-10 | 2448 | 1.2815 | 2.502 | 0.09656 | 2232 | 2.8764 | 3.77 | 173.84 | 0.1213 | 1.369 | 80.801 |
| SKK-11 | 18534 | 2.1003 | 9.144 | 0.08488 | 3985 | 6.92138 | 12.534 | 189.77 | 0.3506 | 12.595 | 42.354 |
| UB(UC-1) | 34008 | 12.9314 | 26.976 | 0.26189 | 10111 | 19.37513 | 29.739 | 146.28 | 4.0062 | 35.27 | 33.446 |
| UB(UC-2) | 1394 | 1.8742 | 1.573 | 0.0675 | 3162 | 0.11939 | 7.132 | 123.6 | 0.0514 | 1.459 | 68.8 |
| UB(UC-3) | 1376 | 9.985 | 3.941 | 0.1956 | 5592 | 1.23314 | 349.471 | 106.04 | 0.4717 | 3.032 | 38.901 |
| UB(UD-1) | 8725 | 5.6373 | 10.667 | 0.17525 | 10188 | 6.13346 | 52.707 | 189.75 | 1.8476 | 11.659 | 24.819 |
| UB(UD-2) | 1169 | 3.174 | 2.399 | 0.14179 | 6144 | 0.45597 | 11.71 | 106.78 | 0.0858 | 1.008 | 99.514 |
| UB(UD-3) | 1419 | 2.1278 | 2.96 | 0.10602 | 7217 | 0.3521 | 113.061 | 171.79 | 0.3511 | 3.834 | 293.667 |
| UB(UK-1) | 1029 | 8.1314 | 1.209 | 0.06563 | 5261 | 0.06132 | 2.729 | 115.67 | 0.0602 | 1.307 | 26.421 |
| UB(UK-2) | 84882 | 5.2631 | 67.294 | 1.07047 | 34855 | 59.23943 | 15.234 | 153 | 15.4225 | 88.665 | 56.41 |
| UB(UK-3) | 60518 | 7.1686 | 62.073 | 0.89535 | 30869 | 38.48763 | 7.242 | 98.43 | 11.8641 | 64.533 | 50.243 |
| UB(UK-4) | 11644 | 7.5949 | 11.549 | 0.29688 | 10588 | 5.96033 | 9.58 | 163.5 | 2.086 | 13.203 | 26.881 |
| UB(UK-5) | 1330 | 3.7672 | 1.91 | 0.08689 | 4918 | 0.55289 | 4.541 | 106.41 | 0.3364 | 1.756 | 27.036 |
| US-01 | 3821 | 1.9382 | 6.175 | 0.10456 | 2336 | 2.08466 | 45.715 | 397.75 | 0.5942 | 4.215 | 24.647 |
| US-02 | 1393 | 2.5004 | 5.241 | 0.06818 | 2875 | 0.20543 | 3.054 | 173.34 | 1.0279 | 12.425 | 38.338 |
| US-03 | 868 | 2.2831 | 1.72 | 0.05245 | 2562 | 0.08819 | 1.464 | 105.07 | 0.6915 | 7.536 | 17.8 |
| USK-01 | 3757 | 8.9359 | 13.642 | 0.08328 | 18343 | 0.16158 | 17.218 | 113.58 | 0.3478 | 4.377 | 31.244 |
| USK-02 | 1314 | 5.5032 | 1.051 | 0.0943 | 16638 | 0.11904 | 22.325 | 99.63 | 0.4377 | 1.169 | 18.786 |
| USK-03 | 15176 | 22.2518 | 32.629 | 0.79592 | 25341 | 4.25442 | 22.979 | 100.08 | 0.9056 | 11.333 | 9.747 |
| USK-04 | 973 | 5.1286 | 0.773 | 0.06945 | 15131 | 0.04643 | 26.782 | 95.16 | 0.0384 | 0.839 | 40.611 |
| USK-05 | 1183 | 5.3961 | 0.963 | 0.07703 | 17360 | 0.06154 | 13.731 | 167.85 | 0.2293 | 1.089 | 24.59 |
| USK-06 | 1018 | 5.2903 | 0.74 | 0.0912 | 16636 | 0.05224 | 15.798 | 159.51 | 0.09 | 1.057 | 40.508 |
| USK-07 | 6404 | 9.752 | 9.242 | 0.16252 | 18830 | 0.31446 | 16.505 | 162.18 | 0.5947 | 5.902 | 21.675 |
| USK-08 | 21622 | 21.5134 | 37.054 | 1.20747 | 26159 | 9.50274 | 28.792 | 210.42 | 0.9692 | 21.048 | 10.316 |
| USK-09 | 1012 | 5.575 | 2.587 | 0.07126 | 17944 | 0.0404 | 21.042 | 149.69 | 0.1553 | 2.2 | 31.18 |
| USK-10 | 1043 | 7.3798 | 3.394 | 0.09823 | 16626 | 0.06327 | 13.575 | 174.2 | 0.1873 | 0.91 | 34.501 |
| ZTAK-01 | 915 | 4.229 | 8.264 | 0.06154 | 19580 | 0.04406 | 207.6 | 266.5 | 0.0717 | 1.595 | 24.06 |

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ZTAK-02 | 990 | 2.903 | 8.555 | 0.06317 | 12530 | 0.01483 | 296.8 | 134.9 | 0.0402 | 1.265 | 24.17 |
| ZTAK-03 | 1229 | 2.814 | 7.071 | 0.05227 | 19120 | 0.0209 | 159.4 | 266.1 | 0.0439 | 1.283 | 35.57 |
| ZTAK-04 | 1281 | 34.89 | 9.232 | 0.05443 | 33720 | 0.03144 | 107.7 | 155.2 | 0.8555 | 2.611 | 8.579 |
| ZTAK-05 | 1700 | 33.45 | 117.9 | 0.1063 | 21650 | 0.07776 | 237.8 | 196.2 | 1.581 | 4.736 | 13.99 |
| ZTAK-06 | 1349 | 16.04 | 6.998 | 0.08312 | 23210 | 0.04347 | 226.5 | 210.1 | 0.4538 | 2.474 | 14.87 |
| ZTAK-07 | 1231 | 22.98 | 9.301 | 0.04559 | 16780 | 0.03208 | 23.45 | 263.4 | 0.2581 | 2.45 | 17.75 |
| ZTAK-08 | 1207 | 12.6 | 9.527 | 0.1183 | 18540 | 0.04724 | 194.4 | 196.5 | 0.2852 | 2.38 | 14.49 |
| ZTAK-09 | 1373 | 11.32 | 14.82 | 0.1511 | 19290 | 0.06931 | 204 | 214.4 | 0.5196 | 2.801 | 18.73 |
| ZTAK-10 | 1063 | 7.957 | 7.066 | 0.04318 | 16840 | 0.02711 | 24.98 | 313.8 | 0.0886 | 2.142 | 17.4 |
| ZTT-01 | 1892 | 52.45 | 4920 | 0.06615 | 54550 | 0.4955 | 669.8 | 148.6 | 2.819 | 47 | 54.05 |
| ZTT-02 | 1523 | 41.72 | 2236 | 0.05878 | 65420 | 0.4757 | 172.3 | 126.9 | 3.129 | 22.82 | 34.81 |
| ZTT-03 | 1592 | 37.38 | 3326 | 0.05382 | 39190 | 0.4193 | 235 | 137.4 | 1.45 | 24.53 | 61.87 |
| ZTT-04 | 1514 | 50.34 | 2518 | 0.06244 | 63500 | 0.5315 | 160.5 | 62.1 | 3.543 | 20.45 | 39.84 |
| ZTT-05 | 1633 | 170.1 | 4098 | 0.09201 | 53870 | 0.8138 | 423.6 | 121.1 | 5.233 | 36.27 | 56.92 |
| ZTT-06 | 1080 | 53.7 | 222.5 | 0.03786 | 30280 | 0.3958 | 273.9 | 165.9 | 0.6289 | 5.898 | 36.2 |
| ZTT-07 | 1612 | 0.5841 | 2.241 | 0.17215 | 2334 | 0.13854 | 3.7 | 98.7 | 0.0936 | 1.761 | 108.51 |
| ZTT-08 | 1204 | 54.42 | 1084 | 0.08185 | 81060 | 0.5746 | 138.5 | 102.9 | 3.725 | 11.11 | 91.31 |
| ZTT-09 | 1972 | 45.81 | 3716 | 0.06229 | 47770 | 0.4524 | 48.01 | 56.4 | 2.681 | 32.99 | 83.48 |
| ZTT-10 | 1070 | 36.5 | 86.14 | 0.04869 | 40970 | 0.3786 | 26.24 | 102.9 | 0.2334 | 1.674 | 111.8 |
| ZUN-01 | 1120 | 12.4797 | 15.578 | 0.03722 | 4410 | 0.08514 | 4.23 | 442.06 | 0.1168 | 3.214 | 20.79 |
| ZUN-02 | 1086 | 15.2697 | 1.404 | 0.05056 | 7417 | 0.07985 | 4.679 | 534.62 | 0.0837 | 2.04 | 24.86 |
| ZUN-03 | 1089 | 19.2626 | 16.37 | 0.05061 | 7964 | 0.09622 | 42.143 | 452 | 0.4978 | 5.37 | 18.331 |
| ZUN-04 | 1489 | 52.1921 | 13.663 | 0.06762 | 19529 | 0.15153 | 88.132 | 748.29 | 0.9862 | 3.471 | 30.739 |
| ZUN-05 | 2840 | 103.5938 | 2778.927 | 0.08621 | 46592 | 0.28995 | 122.946 | 1311.32 | 4.9705 | 45.031 | 65.753 |
| ZUN-06 | 2138 | 71.1968 | 1539.828 | 0.06887 | 37333 | 0.24959 | 106.126 | 1179.33 | 4.5573 | 20.27 | 30.152 |
| ZUN-07 | 1323 | 24.0303 | 32.658 | 0.03064 | 17219 | 0.12811 | 19.32 | 668.5 | 0.5629 | 14.672 | 27.439 |
| ZUN-08 | 1360 | 40.0954 | 445.997 | 0.06363 | 18490 | 0.13738 | 30.91 | 839.51 | 0.5906 | 11.126 | 38.723 |
| ZUN-09 | 1218 | 19.101 | 16.659 | 0.04888 | 13395 | 0.29179 | 5.224 | 11933.54 | 0.2376 | 11.167 | 23.207 |
| ZUN-10 | 1339 | 28.2447 | 88.08 | 0.05245 | 14907 | 0.29558 | 11.433 | 13367.44 | 0.353 | 10.075 | 24.894 |

# APPENDIX 7.4

# INAA DATA FOR STEATITE ARTIFACTS FROM HARAPPA

Elemental data in parts per million (PPM)

| Artifact (year/lot-rec) | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H87/33-02 | 2048 | 0.6936 | 2.012 | 0.0692 | 3658 | 0.16965 | 4.075 | 569.98 | 0.0531 | 3.622 | 93.79 |
| H87/86-228 | 1803 | 1.753 | 6.358 | 0.06166 | 3928 | 0.16071 | 9.868 | 417.28 | 0.0964 | 4.27 | 112.141 |
| H87/86-229 | 2087 | 1.2263 | 2.577 | 0.0554 | 4689 | 0.17738 | 12.586 | 477.79 | 0.0671 | 3.887 | 102.267 |
| H87/86-236 | 2085 | 0.8963 | 2.8 | 0.06142 | 4477 | 0.15191 | 12.228 | 504.37 | 0.1688 | 4.562 | 138.319 |
| H87/237-86 | 2160 | 0.7003 | 2.667 | 0.05617 | 5019 | 0.15229 | 4.626 | 675.22 | 0.0594 | 4.045 | 97.469 |
| H88/340-24 | 1565 | 8.7269 | 8.26 | 0.05768 | 2302 | 0.12548 | 6.918 | 355.27 | 0.0425 | 3.376 | 75.202 |
| H89/1018-13 | 1491 | 0.5875 | 1.092 | 0.05933 | 2154 | 0.1729 | 2.772 | 304.81 | 0.0332 | 0.834 | 76.968 |
| H89/1121-5 | 9444 | 0.8239 | 6.74 | 0.43926 | 2878 | 15.36836 | 4.039 | 693.28 | 1.4736 | 4.571 | 62.038 |
| H2000/2230-14 | 1566 | 0.5745 | 2.339 | 0.3222 | 2530 | 0.0322 | 5.329 | 477.1 | 0.0407 | 2.171 | 113.2 |
| H2000/2230-15 | 1796 | 0.3977 | 6.596 | 0.2777 | 2578 | 0.113 | 6.788 | 404.1 | 0.0735 | 3.864 | 175.6 |
| H2000/2230-16 | 1540 | 0.2525 | 0.992 | 0.48474 | 2116 | 0.08471 | 12.33 | 424.51 | 0.035 | 2.193 | 10.747 |
| H2000/2230-17 | 964 | 0.5984 | 4.444 | 0.49046 | 3228 | 0.09129 | 3.698 | 474.61 | 0.0457 | 1.197 | 15.049 |
| H2000/2301-176 | 1614 | 0.3186 | 1.176 | 0.50474 | 2440 | 0.11467 | 5.805 | 365.22 | 0.0548 | 2.501 | 10.691 |
| H2000/2301-177 | 1675 | 0.4263 | 1.812 | 0.46841 | 2968 | 0.11826 | 4.349 | 435.86 | 0.0685 | 3.264 | 13.189 |
| H2001/2373-10 | 1527 | 0.9361 | 0.89 | 0.12273 | 4391 | 0.0222 | 9.209 | 600.57 | 0.0312 | 0.864 | 166.649 |
| H2000/2753-17 | 1704 | 0.6088 | 0.713 | 0.06119 | 1639 | 0.03378 | 12.172 | 516.82 | 0.0356 | 0.831 | 33.62 |
| H2000/2774-14 | 25996 | 2.4339 | 16.812 | 0.27295 | 7037 | 33.85512 | 17.498 | 961.72 | 1.6237 | 36.504 | 15.681 |
| H2000/2774-15 | 1777 | 0.6635 | 0.63 | 0.09948 | 1640 | 0.05545 | 3.349 | 604.26 | 0.0877 | 0.721 | 16.766 |
| H2000/2789-30 | 1915 | 0.6296 | 1.015 | 0.12053 | 3000 | 0.07677 | 5.179 | 668.02 | 0.0303 | 0.73 | 31.703 |
| H2000/2880-16 | 2178 | 0.7311 | 1.602 | 0.0621 | 2924 | 0.08398 | 22.701 | 744.61 | 0.0269 | 1.188 | 28.404 |
| H90/3030-55 | 1551 | 0.6282 | 0.746 | 0.08979 | 5127 | 0.03268 | 6.408 | 408.17 | 0.0226 | 0.924 | 130.403 |
| H90/3068-50 | 1596 | 0.8657 | 1.411 | 0.0607 | 3877 | 0.03733 | 5.183 | 585.77 | 0.0246 | 1.455 | 88.372 |
| H90/3208-68 | 1414 | 3.48 | 1.612 | 0.4496 | 2479 | 0.03604 | 2.481 | 550.7 | 0.0734 | 1.075 | 20.16 |
| H90/3290-17 | 1561 | 0.6749 | 1.405 | 0.16116 | 1778 | 0.04251 | 2.082 | 737.58 | 0.0654 | 1.904 | 85.343 |
| H93/3534-13 | 2001 | 1.0981 | 3.055 | 0.14927 | 4282 | 0.19795 | 14.556 | 971.62 | 0.0652 | 2.52 | 147.739 |
| H93/3710-16 | 1516 | 0.4904 | 1.976 | 0.07162 | 2517 | 0.0626 | 6.046 | 552.65 | 0.0594 | 1.645 | 59.855 |
| H93/3710-70 | 1747 | 0.6235 | 3.74 | 0.07846 | 2673 | 0.08883 | 9.024 | 719.89 | 0.1316 | 4.178 | 216.293 |
| H93/3808-52 | 1535 | 0.5978 | 0.705 | 0.11724 | 1757 | 0.03949 | 2.866 | 584.69 | 0.0595 | 0.938 | 83.005 |
| H93/3869-24 | 1545 | 0.948 | 0.713 | 0.0534 | 2080 | 0.07567 | 6.785 | 431.07 | 0.0501 | 0.903 | 73.704 |
| H95/4453-22 | 1468 | 0.6378 | 0.936 | 0.07793 | 2988 | 0.02537 | 5.263 | 532.65 | 0.03 | 0.92 | 128.348 |
| H95/4613-42 | 1626 | 0.4385 | 0.498 | 1.14059 | 1480 | 0.04576 | 6.963 | 669.88 | 0.0721 | 1.332 | 35.312 |
| H95/4615-94 | 1897 | 1.0672 | 1.057 | 0.08311 | 3835 | 0.20093 | 8.262 | 660.78 | 0.1029 | 1.215 | 63.778 |
| H95/4723-2 | 1328 | 0.5706 | 2.034 | 0.05157 | 2667 | 0.16767 | 27.227 | 707.18 | 0.1308 | 1.543 | 64.732 |
| H95/4726-101 | 1910 | 0.4867 | 1.063 | 0.04422 | 1694 | 0.06002 | 4.057 | 708.36 | 0.0364 | 1.595 | 84.159 |
| H95/4746-7 | 1516 | 0.6595 | 0.687 | 0.05577 | 2212 | 0.0283 | 1.82 | 541.39 | 0.0358 | 1.167 | 103.45 |
| H95/4751-8 | 1885 | 0.5744 | 0.819 | 0.11345 | 2635 | 0.13825 | 20.026 | 1041.44 | 0.0939 | 1.643 | 32.813 |
| H95/4919-62 | 1185 | 0.7353 | 1.672 | 0.07132 | 2359 | 0.49272 | 51.771 | 564.43 | 0.2421 | 1.981 | 13.615 |
| H95/4950-4 | 1673 | 0.66 | 0.537 | 0.12262 | 2845 | 0.02256 | 4.6 | 609.57 | 0.0379 | 1.105 | 36.725 |
| H95/4954-18 | 1322 | 0.4472 | 0.974 | 0.09818 | 1938 | 0.02474 | 3.828 | 647.4 | 0.0331 | 0.813 | 22.447 |
| H95/4961-176 | 1433 | 0.6354 | 0.779 | 0.11414 | 3345 | 0.04042 | 3.845 | 682.24 | 0.0503 | 1.064 | 23.343 |
| H94/5135-34 | 1990 | 0.391 | 7.257 | 0.14091 | 1226 | 0.098 | 2.279 | 507.23 | 0.129 | 1.821 | 72.69 |
| H95/5184-1 | 1254 | 0.5649 | 0.969 | 0.08989 | 2155 | 0.02363 | 3.77 | 327.9 | 0.032 | 0.84 | 103.985 |
| H95/5713-145 | 1810 | 0.7737 | 1.266 | 0.06631 | 2268 | 0.03384 | 7.164 | 697.78 | 0.1004 | 1.636 | 89.964 |
| H95/5734-31 | 1590 | 1.2582 | 1 | 0.07435 | 2617 | 0.03433 | 4.885 | 608.96 | 0.0404 | 1.268 | 100.125 |
| H95/5747-125 | 1529 | 0.5098 | 1.075 | 0.06686 | 2639 | 0.03519 | 4.464 | 489.91 | 0.0291 | 1.161 | 63.928 |
| H95/5749-97 | 1363 | 0.7542 | 0.635 | 0.08768 | 3423 | 0.03623 | 4.201 | 643.82 | 0.0161 | 1.046 | 122.396 |
| H95/5759-25 | 1636 | 0.712 | 0.851 | 0.04045 | 2842 | 0.03462 | 3.704 | 567.39 | 0.0323 | 1.587 | 77.658 |
| H95/5763-19 | 1571 | 0.8232 | 0.758 | 0.07527 | 2626 | 0.04487 | 10.005 | 750.27 | 0.0431 | 1.799 | 141.979 |

| Artifact (year/lot-rec) | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H95/5802-5 | 2091 | 0.8686 | 0.809 | 0.4075 | 3753 | 0.08015 | 66.755 | 620.2 | 0.0589 | 0.985 | 82.87 |
| H95/5803-25 | 1655 | 0.7372 | 1.692 | 0.14813 | 6033 | 0.11117 | 174.265 | 703.34 | 0.0581 | 0.897 | 288.355 |
| H95/5820-11a | 1261 | 0.6224 | 1.077 | 0.08811 | 1363 | 0.03201 | 1.892 | 477.13 | 0.0148 | 0.86 | 105.058 |
| H96/5837-18 | 1326 | 0.3213 | 0.528 | 0.12375 | 1978 | 0.02819 | 4.856 | 539.61 | 0.0388 | 0.962 | 191.366 |
| H96/6218-8 | 1592 | 1.1237 | 0.673 | 0.128 | 3572 | 0.09552 | 2.989 | 1138.76 | 0.0787 | 1.109 | 24.592 |
| H96/6219-44 | 1309 | 0.4862 | 0.668 | 0.06733 | 1922 | 0.03336 | 11.306 | 458.98 | 0.0391 | 0.965 | 37.301 |
| H96/6234-2 | 1303 | 0.4887 | 0.607 | 0.07568 | 2316 | 0.0272 | 4.065 | 392.41 | 0.0314 | 0.773 | 97.483 |
| H96/6257-21 | 1430 | 1.0858 | 0.545 | 0.14628 | 4108 | 0.02347 | 3.656 | 467.05 | 0.0325 | 0.836 | 168.416 |
| H95/6509-97 | 1958 | 0.4702 | 1.517 | 0.07118 | 4777 | 0.10161 | 22.064 | 722.29 | 0.023 | 1.582 | 41.605 |
| H96/7105-8 | 1835 | 0.5276 | 0.645 | 1.15691 | 2313 | 0.05698 | 4.923 | 593.76 | 0.0537 | 1.082 | 42.632 |
| H96/7106-27 | 1574 | 0.3944 | 0.804 | 0.07924 | 2250 | 0.39446 | 88.955 | 593.87 | 0.1138 | 1.932 | 97.271 |
| H96/7118-9 | 1717 | 0.7717 | 1.605 | 0.1395 | 2492 | 0.37042 | 61.076 | 661.47 | 0.0771 | 1.86 | 141.859 |
| H96/7153-14 | 2054 | 0.8125 | 1.224 | 0.07762 | 4670 | 0.0741 | 6.651 | 906.99 | 0.1039 | 1.653 | 126.13 |
| H96/7156-14 | 1714 | 0.3722 | 1.675 | 0.09426 | 2597 | 0.05294 | 5.61 | 447.65 | 0.1029 | 1.39 | 68.086 |
| H96/7239-26 | 1780 | 0.6479 | 1.934 | 0.07958 | 2038 | 0.09767 | 4.859 | 529.28 | 0.1028 | 1.587 | 17.117 |
| H96/7256-43 | 1537 | 0.6898 | 0.913 | 0.13925 | 3190 | 0.12141 | 8.093 | 505.38 | 0.0545 | 0.802 | 23.826 |
| H96/7257-46 | 4060 | 0.7658 | 2.596 | 0.04421 | 2098 | 0.03628 | 2.383 | 782.5 | 0.0265 | 1.31 | 27.685 |
| H96/7333-22 | 4291 | 0.8249 | 1.927 | 0.12301 | 2395 | 0.58948 | 9.824 | 683.5 | 1.0023 | 2.159 | 38.809 |
| H96/7358-11 | 2105 | 0.9389 | 1.213 | 0.12895 | 3465 | 0.23081 | 19.331 | 880.46 | 0.0807 | 1.881 | 141.163 |
| H96/7401-63 | 17284 | 1.2007 | 23.644 | 0.28853 | 4619 | 10.60924 | 22.63 | 682.77 | 2.2431 | 14.211 | 18.2 |
| H96/7410-1 | 543 | 0.4993 | 1.524 | 1.195 | 2470 | 0.07171 | 1.064 | 154.5 | 0.0619 | 0.567 | 15.33 |
| H96/7410-2 | 1598 | 0.5093 | 1.614 | 0.22257 | 2531 | 0.06751 | 2.844 | 429.15 | 0.0437 | 0.911 | 88.935 |
| H96/7414-46 | 8029 | 0.7899 | 5.574 | 0.21674 | 2249 | 2.19513 | 6.818 | 656.71 | 0.8936 | 6.146 | 54.917 |
| H96/7414-47 | 1857 | 0.5334 | 1.637 | 0.5947 | 4501 | f3208 | 33.72 | 652.3 | 0.0789 | 1.201 | 16.79 |
| H96/7467-658 | 88516 | 2.329 | 113.877 | 2.477 | 12741 | 63.574 | 45.889 | 2722.55 | 8.224 | 64.292 | 43.999 |
| H96/7467-790 | 1667 | 0.7843 | 0.836 | 0.1335 | 2202 | 0.08082 | 17.419 | 766.14 | 0.0303 | 1.355 | 28.503 |
| H96/7531-16 | 2071 | 0.8768 | 5.165 | 0.09811 | 4541 | 0.11687 | 4.681 | 1270.88 | 0.0891 | 1.759 | 41.952 |
| H97/7619-3 | 1655 | 0.3622 | 3.502 | 0.10151 | 2614 | 0.18101 | 6.656 | 438.45 | 0.103 | 2.435 | 102.207 |
| H99/7636-8 | 2124 | 1.2381 | 1.807 | 0.06132 | 6026 | 0.24069 | 58.721 | 534.99 | 0.0779 | 16.563 | 98.514 |
| H99/7637-32 | 1853 | 1.445 | 1.633 | 0.04334 | 4703 | 0.16588 | 35.718 | 415.95 | 0.0976 | 3.219 | 122.39 |
| H99/7638-1 | 1869 | 0.4164 | 2.611 | 0.10212 | 4935 | 0.11426 | 4.396 | 479.11 | 0.091 | 12.891 | 71.325 |
| H99/7649-42 | 1970 | 0.7385 | 1.528 | 0.12647 | 2681 | 0.04569 | 5.374 | 529.31 | 0.0688 | 2.122 | 154.091 |
| H97/7780-10 | 1603 | 0.5884 | 0.719 | 0.10167 | 2123 | 0.09512 | 4.09 | 687.75 | 0.4052 | 1.764 | 63.166 |
| H97/7780-8 | 3186 | 0.8741 | 2.777 | 0.07543 | 2160 | 0.22341 | 7.285 | 486.41 | 0.5741 | 1.684 | 74.104 |
| H97/7780-9 | 1566 | 0.429 | 2.361 | 0.04539 | 1860 | 0.21949 | 4.498 | 795.76 | 0.0511 | 1.472 | 125.591 |
| H97/7784-156 | 2053 | 0.8499 | 0.836 | 0.5271 | 2849 | 5.32711 | 5.474 | 473.19 | 0.368 | 1.012 | 9.679 |
| H97/7784-157 | 5922 | 0.6855 | 1.363 | 0.382 | 5327 | 0.02745 | 27.82 | 1240 | 0.0529 | 3.268 | 85.38 |
| H97/7784-158 | 8606 | 0.794 | 0.704 | 0.6222 | 4137 | 0.03545 | 16.42 | 2096 | 0.7103 | 5.714 | 68.53 |
| H97/7784-159 | 18390 | 0.9886 | 3.241 | 0.5797 | 2606 | 1.87 | 8.889 | 3009 | 1.317 | 11.82 | 49.26 |
| H97/7784-16 | 1983 | 0.6449 | 0.702 | 0.4285 | 3939 | 0.02739 | 4.329 | 494 | 0.0119 | 0.897 | 147.3 |
| H97/7784-17 | 1757 | 0.4613 | 1.467 | 0.50166 | 2628 | 0.06017 | 3.02 | 527.33 | 0.0518 | 0.861 | 10.816 |
| H97/7784-18 | 1664 | 1.0544 | 4.001 | 0.54321 | 2415 | 0.07093 | 5.113 | 514.83 | 0.0363 | 0.648 | 10.209 |
| H97/7784-19 | 9294 | 1.4114 | 6.768 | 0.53097 | 4495 | 3.51956 | 4.131 | 663.97 | 1.6514 | 4.731 | 6.293 |
| H97/7784-20 | 1881 | 1.2938 | 3.631 | 0.50932 | 2057 | 0.03803 | 3.115 | 421.69 | 0.0495 | 0.864 | 9.737 |
| H97/7784-21 | 1612 | 52.08 | 3192 | 0.1046 | 55550 | 0.5403 | 32.35 | 15090 | 3.567 | 18.15 | 64.04 |
| H97/7784-22 | 1884 | 0.2482 | 1.374 | 0.49488 | 2878 | 0.06257 | 3.104 | 511.5 | 0.0965 | 1.445 | 6.524 |
| H97/7784-23 | 1863 | 0.5209 | 1.233 | 0.328 | 2688 | 0.07389 | 3.323 | 400 | 0.1574 | 1.032 | 130.3 |
| H97/7784-24 | 19440 | 1.676 | 15.71 | 0.3225 | 5417 | 9.882 | 11.63 | 646.3 | 2.107 | 3.188 | 78.86 |
| H97/7784-25 | 1560 | 0.458 | 0.829 | 0.46907 | 2315 | 0.05173 | 3.012 | 455.18 | 0.0401 | 0.813 | 10.109 |
| H97/7784-27 | 2104 | 13.225 | 81.349 | 0.49928 | 1861 | 0.28395 | 4.99 | 496.58 | 0.6556 | 2.831 | 6.574 |
| H97/7784-28 | 2054 | 0.478 | 1.415 | 0.5038 | 2696 | 0.05971 | 4.46 | 591.89 | 0.0961 | 2.201 | 9.067 |
| H97/7784-29 | 1910 | 0.4477 | 1.656 | 0.47837 | 2512 | 0.12922 | 18.28 | 544.17 | 0.1083 | 1.69 | 9.351 |
| H97/7784-30 | 513 | 0.4103 | 1.39 | 0.13002 | 2989 | 0.0309 | 1.103 | 450.69 | 0.0513 | 0.442 | 88.492 |
| H97/7784-31 | 617 | 0.4982 | 5.937 | 0.3469 | 2330 | 1.131 | 9.594 | 142.6 | 0.1273 | 0.832 | 119.4 |
| H99/7794-3 | 4600 | 0.2839 | 2.942 | 0.08072 | 3717 | 0.17823 | 4.555 | 340.42 | 0.1448 | 6.035 | 142.601 |
| H98/8342-3 | 7107 | 1.035 | 8.298 | 0.17775 | 3715 | 7.42393 | 5.943 | 797.95 | 1.4574 | 5.82 | 11.459 |
| H98/8355-2 | 1888 | 0.5139 | 1.232 | 0.10985 | 2867 | 0.05477 | 1.446 | 709.22 | 0.0816 | 1.462 | 64.64 |

| Artifact (year/lot-rec) | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H98/8364-5 | 2051 | 0.4365 | 1.221 | 0.05151 | 2313 | 0.11733 | 4.458 | 557.29 | 0.1947 | 1.906 | 55.086 |
| H98/8407-39 | 1778 | 0.9304 | 4.195 | 1.265 | 1728 | 0.2508 | 53.41 | 442.1 | 0.0579 | 1.64 | 13.68 |
| H98/8407-40 | 1269 | 1.111 | 3.121 | 1.31 | 2116 | 1.988 | 1.648 | 106.9 | 1.316 | 1.024 | 7.676 |
| H98/8410-12 | 9141 | 1.1994 | 9.302 | 0.23644 | 2627 | 6.47423 | 8.383 | 691.46 | 1.1734 | 5.834 | 43.818 |
| H98/8486-50 | 1718 | 1.287 | 5.323 | 0.3346 | 3235 | 2.556 | 1.362 | 174.6 | 0.6837 | 1.516 | 105.6 |
| H98/8487-32 | 1907 | 0.4496 | 0.698 | 0.848 | 2740 | 0.0549 | 3.669 | 483.3 | 0.0284 | 0.762 | 9.459 |
| H98/8487-33 | 760 | 1.7753 | 9.249 | 0.16709 | 1329 | 0.06247 | 1.402 | 424.39 | 0.0222 | 0.575 | 102.432 |
| H99/8490-103 | 241 | 0.5523 | 2.182 | 0.107 | 1602 | 0.28657 | 3.488 | 668.31 | 0.0984 | 0.44 | 95.468 |
| H99/8492-229 | 1068 | 0.5015 | 1.139 | 1.114 | 810 | 0.3548 | 5.865 | 340.5 | 0.0698 | 1.193 | 13.77 |
| H99/8497-3 | 1465 | 0.5716 | 1.987 | 0.15151 | 2199 | 0.40107 | 26.21 | 490.13 | 0.1389 | 1.539 | 76.924 |
| H98/8668-2 | 1825 | 24.986 | 671.41 | 0.88296 | 33729 | 0.14137 | 59.035 | 443.16 | 1.3826 | 9.412 | 317.395 |
| H99/8760-77 | 2185 | 0.6666 | 4.872 | 0.06074 | 7353 | 0.08911 | 7.656 | 1099.17 | 0.0375 | 17.62 | 85.628 |
| H99/8956-1 | 582 | 0.6865 | 1.05 | 1.339 | 4824 | 0.06759 | 2.152 | 222.8 | 0.0584 | 0.583 | 22.83 |
| H2000/8983-44 | 1686 | 0.428 | 0.994 | 0.5192 | 2389 | 0.3261 | 26.45 | 668.4 | 0.1156 | 2.401 | 14.82 |
| H2000/8992-1 | 2129 | 0.267 | 1.082 | 1.034 | 5480 | 0.08161 | 8.968 | 524.1 | 0.0369 | 1.329 | 11.48 |
| H2000/8997-4 | 1993 | 0.3954 | 0.652 | 1.055 | 2793 | 0.04022 | 4.007 | 476.3 | 0.036 | 0.913 | 12.34 |
| H2000/9442-2 | 6493 | 1.4664 | 6.495 | 0.19253 | 2491 | 4.01521 | 12.58 | 347.38 | 0.7164 | 3.745 | 67.164 |
| H2000/9443-6 | 13130 | 1.0476 | 6.338 | 0.31612 | 3968 | 12.67332 | 5.966 | 598.01 | 1.2442 | 6.264 | 47.379 |
| H2000/9443-7 | 1136 | 0.33 | 2.319 | 1.021 | 9097 | 0.05017 | 3.527 | 255.6 | 0.0424 | 0.946 | 10.14 |
| H2000/9445-1 | 54600 | 0.4794 | 1.643 | 1.636 | 3285 | 0.06579 | 600 | 10000 | 0.075 | 90 | 11.19 |
| H2000/9445-2 | 392 | 0.5189 | 1.437 | 0.21518 | 3615 | 0.15337 | 13.21 | 519.23 | 0.1468 | 0.424 | 91.974 |
| H2000/9447-5 | 7535 | 1.402 | 14.37 | 1.157 | 4953 | 18.94 | 4.595 | 293 | 1.941 | 3.008 | 11.03 |
| H2000/9514-93 | 1964 | 0.4098 | 1.126 | 0.07465 | 2718 | 0.05535 | 4.49 | 468.36 | 0.0535 | 1.092 | 18.043 |
| H99/9737-22 | 1331 | 1.0386 | 0.682 | 0.1272 | 2807 | 0.02977 | 1.344 | 367.15 | 0.0248 | 0.969 | 149.973 |
| H99/9747-33 | 1715 | 0.6065 | 0.709 | 0.1186 | 2869 | 0.10796 | 5.54 | 738.14 | 0.0553 | 1.347 | 127.436 |
| H99/9756-16 | 1487 | 0.5775 | 1.039 | 0.06759 | 2551 | 0.02069 | 4.48 | 486.93 | 0.038 | 1.37 | 149.495 |
| H99/9779-4 | 1496 | 0.5006 | 1.104 | 0.10644 | 3218 | 0.03175 | 4.131 | 446.97 | 0.0705 | 2.233 | 163.126 |
| H2000/9840-8 | 22771 | 1.7333 | 19.051 | 0.12146 | 7585 | 0.38133 | 11.975 | 785.5 | 1.2201 | 15.289 | 141.286 |
| H2000/9973-13 | 657 | 0.2368 | 0.75 | 0.9334 | 3267 | 0.1066 | 19.39 | 150.7 | 0.0175 | 0.767 | 18.9 |
| H2000/11001-6 | 1990 | 0.4956 | 1.194 | 0.192 | 5136 | 0.0648 | 6.8318 | 502.81 | 0.0555 | 5.661 | 27.62 |
| H2001/2913-12 | 1920 | 0.8082 | 0.754 | 0.31509 | 3359 | 0.14078 | 7.871 | 801.75 | 0.0484 | 1.113 | 74.926 |
| H2001/2920-7 | 1111 | 0.6078 | 0.886 | 0.12777 | 3045 | 0.03029 | 3.725 | 361.35 | 0.0387 | 0.737 | 120.657 |
| H2001/2922-6 | 1414 | 0.5917 | 0.556 | 0.05952 | 2376 | 0.05637 | 5.415 | 293.21 | 0.039 | 0.934 | 98.276 |
| H2001/2939-25 | 1550 | 0.9066 | 1.644 | 0.07531 | 8401 | 0.31191 | 179.866 | 384.3 | 0.1217 | 1.916 | 95.45 |
| H2001/11562-26 | 2158 | 0.5767 | 2.124 | 0.12408 | 2657 | 0.07452 | 6.15 | 790.88 | 0.0694 | 3.373 | 18.882 |
| H2001/11923-9 | 1834 | 0.6998 | 1.133 | 0.09334 | 2047 | 0.03676 | 4.341 | 599.76 | 0.099 | 1.063 | 23.414 |

# APPENDIX 7.5
# INAA DATA FOR UNFIRED STEATITE ARTIFACTS FROM MOHENJO-DARO (MD)

Elemental data in parts per million (PPM)

| Sample / Area | Parent-rock 1st & 2nd PGM | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MD-S1 / DK-A | SB / SKK | 1744 | 0.2975 | 1.628 | 0.08737 | 2181 | 0.11994 | 4.882 | 709.45 | 0.0628 | 1.591 | 30.013 |
| MD-S2 / DK-A | PD / SKK | 2106 | 0.8963 | 1.627 | 0.07933 | 2438 | 0.08497 | 5.947 | 936.66 | 0.0394 | 1.353 | 45.075 |
| MD-S3 / DK-A | SKK / SB | 2140 | 0.6876 | 3.459 | 0.08595 | 3229 | 0.19026 | 9.672 | 775.72 | 0.0795 | 1.278 | 26.517 |
| MD-S4 / DK-A | ATM / SB | 1481 | 0.8113 | 3.792 | 0.0629 | 3316 | 0.10597 | 4.724 | 852.45 | 0.0756 | 2.505 | 31.386 |
| MD-S5 / DK-A | ATM / SKK | 1441 | 0.8831 | 1.853 | 0.09926 | 5241 | 0.23115 | 6.751 | 1214.59 | 0.0697 | 1.47 | 34.255 |
| MD-S6 / DK-A | ATM / ANB | 1553 | 0.9122 | 1.345 | 0.08971 | 1956 | 0.13561 | 5.746 | 1686.97 | 0.0544 | 2.723 | 21.419 |
| MD-S7 / Moneer | SB / SKK | 820 | 0.8168 | 1.331 | 0.07102 | 5367 | 0.04619 | 2.88 | 679.55 | 0.099 | 1.471 | 30.777 |
| MD-S8 / Moneer | ATM / SB | 1858 | 1.0956 | 1.348 | 0.04398 | 4215 | 0.08384 | 7.104 | 1318.33 | 0.072 | 2.539 | 30.532 |
| MD-S9 / Moneer | ANB / ATM | 3361 | 1.6533 | 2.889 | 0.08035 | 4775 | 1.30215 | 23.849 | 7552.83 | 0.389 | 5.474 | 35.939 |
| MD-S10 / Moneer | PD / GMP | 1828 | 4.44 | 1.837 | 0.07191 | 3923 | 0.30075 | 16.615 | 300.98 | 0.1155 | 3.508 | 18.608 |
| MD-S11 / Moneer | SB / SC | 1671 | 0.6067 | 1.92 | 0.06065 | 2389 | 0.1423 | 9.755 | 326.63 | 0.0801 | 1.646 | 25.208 |
| MD-S12 / DK-A | SC / SB | 1938 | 0.4789 | 1.838 | 0.07169 | 2302 | 0.36967 | 13.907 | 526.06 | 0.1618 | 3.004 | 19.741 |
| MD-S13 / DK-A | RDP / ATM | 1613 | 0.6379 | 1.55 | 0.06836 | 2793 | 0.42014 | 151.612 | 1090.83 | 0.2931 | 1.703 | 12.789 |
| MD-S14 / DK-A | PD / SKK | 4063 | 1.204 | 3.688 | 0.06431 | 2483 | 0.10103 | 8.315 | 531.95 | 0.0384 | 1.623 | 46.903 |
| MD-S15 / DK-A | SB / SKK | 1539 | 0.4198 | 3.213 | 0.05401 | 2984 | 0.32981 | 8.809 | 381.28 | 0.0875 | 1.799 | 30.494 |

# APPENDIX 7.6
# INAA DATA FOR UNFIRED STEATITE ARTIFACTS FROM MEHRGARH (MR) AND NAUSHARO (NS)

Elemental data in parts per million (PPM)

| Sample [artifact context / number] | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MR-s1 [MR4 Atelier] | 2143 | 0.2647 | 15.234 | 0.10067 | 609 | 0.1043 | 8.222 | 979.05 | 0.1783 | 20.02 | 6.816 |
| MR-s2 [MR4 Atelier] | 1847 | 0.2706 | 12.179 | 0.10085 | 439 | 0.099 | 5.676 | 860.26 | 0.1486 | 15.21 | 6.593 |
| MR-s3 [MR4 Atelier] | 2629 | 0.2604 | 26.586 | 0.08776 | 961 | 0.1291 | 5.179 | 1198.54 | 0.285 | 23.35 | 8.364 |
| MR-s4 [MR4 Atelier] | 1945 | 0.2434 | 37.275 | 0.0755 | 523 | 0.379 | 4.763 | 1350.85 | 0.1789 | 66.95 | 4.277 |
| MR-s5 [MR4 Atelier] | 1403 | 0.1697 | 18.895 | 0.0732 | 356 | 0.4688 | 6.261 | 1037.41 | 0.1335 | 68.82 | 5.582 |
| MR-s6 [MR4 Atelier] | 1786 | 0.1874 | 20.7595 | 0.0855 | 584 | 0.1371 | 5.681 | 1409.39 | 0.2706 | 105.7 | 7.646 |
| MR-s7 [MR4 Atelier] | 1987 | 0.4336 | 40.389 | 0.0946 | 1135 | 0.2655 | 8.8041 | 1476.75 | 0.2175 | 84.12 | 7.618 |
| MR-s8 [MR.99.03.145.12] | 2553 | 0.4108 | 15.326 | 0.0956 | 477 | 0.4933 | 14.28 | 1183.66 | 0.1702 | 26.26 | 7.327 |
| MR-s9 [MR.00.3S.508.08] | 3468 | 174.66 | 7407.3 | 0.0966 | 66212 | 0.116 | 294.9 | 208.78 | 2.1511 | 30.7 | 37.097 |
| MR-s10 [MR.00.03.390] | 3430 | 0.4513 | 41.0334 | 0.4934 | 1078 | 0.1338 | 5.548 | 1198.18 | 0.3797 | 83.05 | 11.278 |
| MR-s11 [MR.00.03.109.115] | 62049 | 71.218 | 387.088 | 0.0519 | 112956 | 15.754 | 1876.2 | 190.48 | 104.7 | 574.5 | 12.001 |
| MR-s12 [MR.98.03.87.02] | 3184 | 0.8116 | 42.3403 | 0.0945 | 1970 | 0.0865 | 13.181 | 2201.85 | 0.3861 | 72.1 | 6.662 |
| MR-s13 [MR.00.03.183.219] | 1386 | 41.617 | 1472.49 | 0.0835 | 34553 | 0.0845 | 38.83 | 308.17 | 1.2495 | 7.882 | 17.41 |
| NS-s1 [NS.90.09.21.02] | 1408 | 118.14 | 1826.7 | 0.06186 | 12059 | 0.1655 | 135.03 | 428.62 | 1.203 | 9.199 | 14.256 |

## APPENDIX 7.7

## INAA DATA FOR UNFIRED STEATITE ARTIFACTS FROM GOLA DHORO (GD), NAGWADA (NGW), UNKNOWN LORALAI SITE (LOR), TEPE HISSAR (TH) AND MITATHAL (MTL)

Elemental data in parts per million (PPM)

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GD-s1 | 11371 | 85.764 | 2546.5 | 0.3223 | 35012 | 0.07018 | 132.05 | 1892.7 | 2.2341 | 23.132 | 62.057 |
| NGW-s1 | 8243 | 57.7813 | 894.3 | 0.07159 | 23523 | 0.03659 | 313.105 | 133.47 | 4.3543 | 25.202 | 10.412 |
| LOR-s1 | 191700 | 0.352 | 7.579 | 3.358 | 3070 | 36.58 | 6.941 | 250.4 | 3.61 | 8.385 | 30.25 |
| LOR-s2 | 2174 | 48.2109 | 4262.9 | 0.0925 | 43246 | 0.5044 | 106.2584 | 427.34 | 2.9106 | 33.7013 | 16.785 |
| TH-s1 | 1336 | 6.1175 | 1.2358 | 0.1375 | 28101 | 0.3156 | 88.1441 | 951.29 | 0.0571 | 4.819 | 128.74 |
| TH-s2 | 36727 | 1.1252 | 84.56 | 0.1183 | 13020 | 4.8644 | 32.5707 | 745.67 | 4.0722 | 102.23 | 10.286 |
| TH-s3 | 1219 | 3.4656 | 1.7806 | 0.138 | 14026 | 1.009 | 163.3491 | 332.54 | 0.101 | 1.5844 | 101.64 |
| TH-s4 | 1221 | 2.8522 | 0.9222 | 0.0932 | 7627 | 0.0502 | 27.5931 | 1122.9 | 0.0657 | 1.9529 | 22.322 |
| MTL-1 | 2272 | 2.264 | 2.87 | 4.018 | 1939 | 0.9789 | 16.23 | 1457 | 0.0614 | 9.567 | 16.13 |

# APPENDIX 7.8

## STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS FOR SCATTERPLOTS IN CHAPTER 7 GENERATED USING CANONICAL DISCRIMINANT ANALYSIS

| Figures 7.31 & 7.32 | Function 1 | Function 2 |
|---|---|---|
| Log Al | .062 | -.504 |
| Log Co | 1.303 | .937 |
| Log Cr | .605 | -1.100 |
| Log Eu | -.089 | -.043 |
| Log Fe | -1.363 | -.884 |
| Log La | -.442 | .318 |
| Log Mn | .278 | -.239 |
| Log Na | .237 | .452 |
| Log Sc | .513 | .573 |
| Log V | -.449 | .940 |
| Log Zn | .072 | .198 |

| Figure 7.34 | Function 1 | Function 2 |
|---|---|---|
| Log Al | .791 | .059 |
| Log Co | -.091 | -.547 |
| Log Cr | .423 | .097 |
| Log Eu | .442 | .350 |
| Log Fe | .256 | .372 |
| Log La | .200 | 1.120 |
| Log Mn | .363 | -.147 |
| Log Na | -.753 | -.054 |
| Log Sc | -.418 | -.551 |
| Log V | -.657 | -.224 |
| Log Zn | .261 | -.321 |

| Figure 7.35 | Function 1 | Function 2 |
|---|---|---|
| Log Al | -.333 | -.670 |
| Log Co | 1.599 | -.657 |
| Log Cr | -.369 | .226 |
| Log Eu | -.069 | -.042 |
| Log Fe | -1.829 | .676 |
| Log La | -.120 | -.213 |
| Log Mn | .199 | .671 |
| Log Na | .382 | .612 |
| Log Sc | 1.005 | -.670 |
| Log V | .373 | .896 |
| Log Zn | .261 | -.081 |

| Figure 7.38 | Function 1 | Function 2 |
|---|---|---|
| Log Al | -.515 | -.295 |
| Log Co | .670 | -1.114 |
| Log Cr | .323 | .353 |
| Log Eu | -.313 | -.071 |
| Log Fe | -.826 | 1.306 |
| Log La | -.134 | -.037 |
| Log Mn | .307 | .269 |
| Log Na | .724 | .479 |
| Log Sc | .661 | -.455 |
| Log V | .206 | .119 |
| Log Zn | -.071 | -.347 |

| Figure 7.39 A & B | Function 1 | Function 2 |
|---|---|---|
| Log Al | -.803 | -.248 |
| Log Co | .317 | 1.304 |
| Log Cr | .226 | -.129 |
| Log Eu | -.106 | -.299 |
| Log Fe | -.545 | -.550 |
| Log La | -.019 | .099 |
| Log Mn | .800 | -.489 |
| Log Na | .157 | .597 |
| Log Sc | -.122 | -.087 |
| Log V | 1.011 | .290 |
| Log Zn | .302 | -.333 |

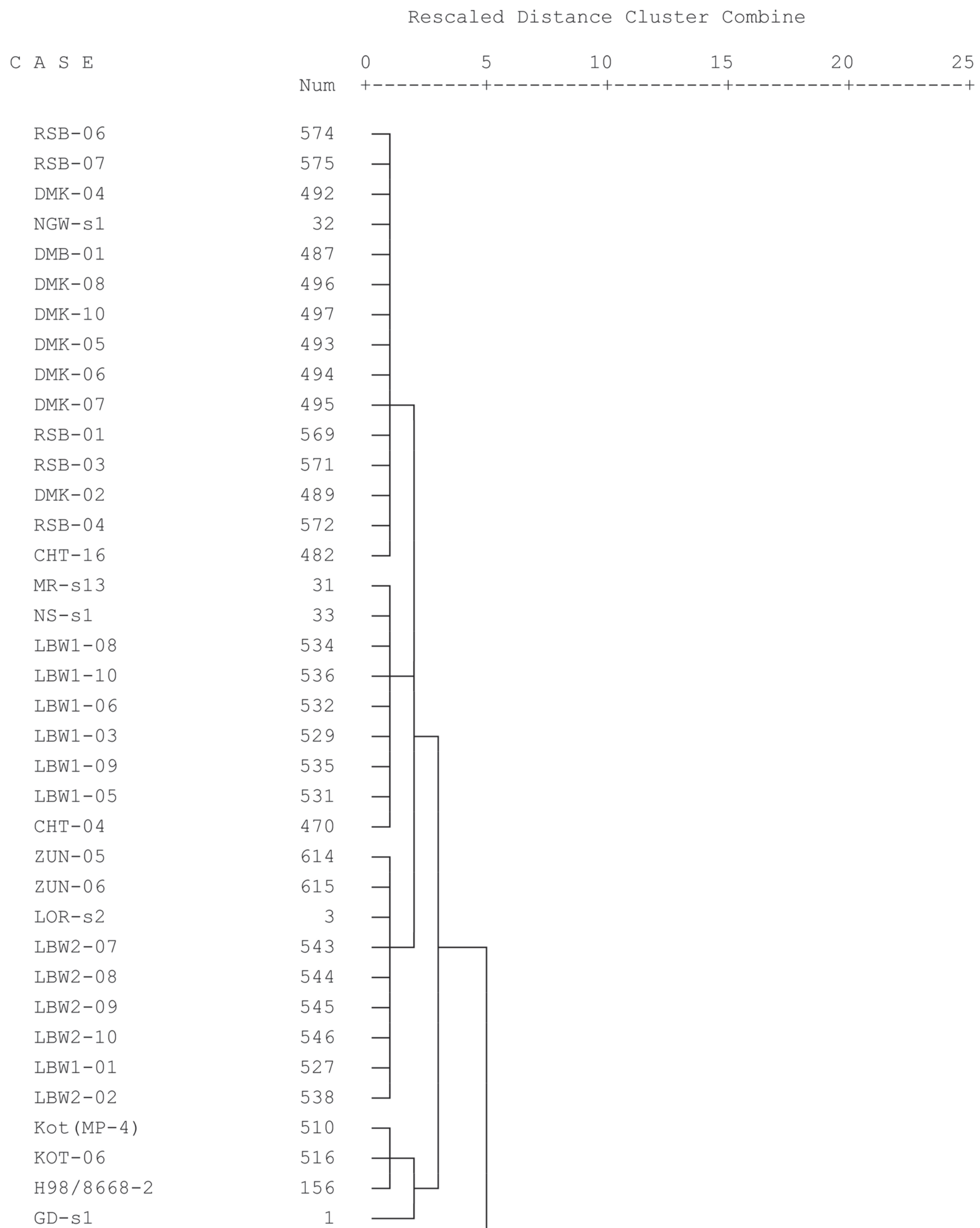
| Figure 7.45 | Function 1 | Function 2 |
|---|---|---|
| Log Al | .611 | .670 |
| Log Co | -.272 | 1.176 |
| Log Cr | .079 | -.450 |
| Log Eu | .597 | .371 |
| Log Fe | .621 | -1.218 |
| Log La | .160 | -.083 |
| Log Mn | 1.092 | .018 |
| Log Na | -1.241 | -.088 |
| Log Sc | -.073 | .178 |
| Log V | -.616 | .098 |
| Log Zn | .613 | .273 |

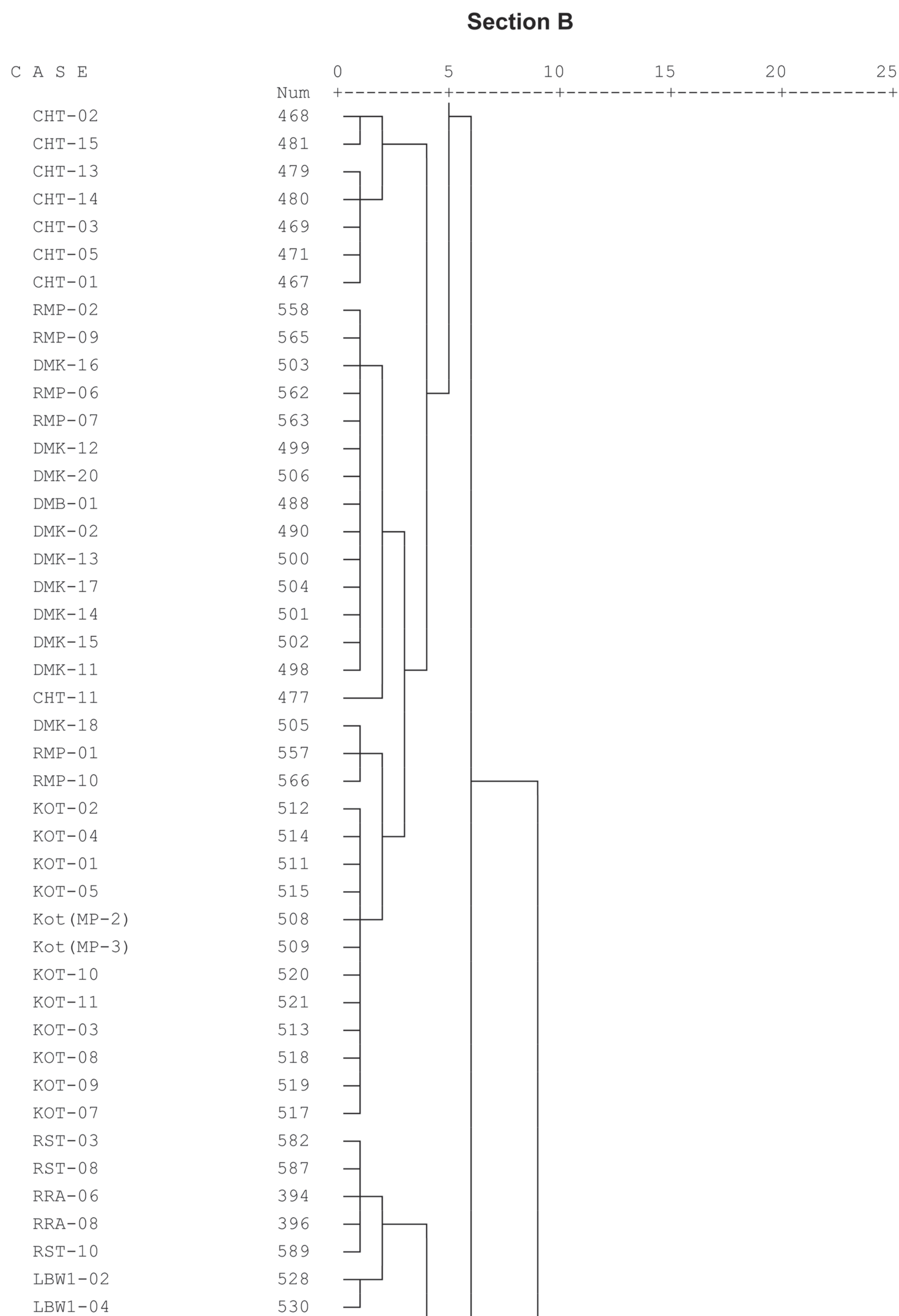
| Figure 7.47 | Function 1 | Function 2 |
|---|---|---|
| Log Al | -1.462 | -.304 |
| Log Co | .189 | 1.060 |
| Log Cr | -.985 | -.069 |
| Log Eu | -.209 | -.704 |
| Log Fe | .152 | -1.252 |
| Log La | .293 | .155 |
| Log Mn | .146 | -.216 |
| Log Na | -.497 | .515 |
| Log Sc | -.054 | .646 |
| Log V | 1.808 | .208 |
| Log Zn | 1.083 | .689 |

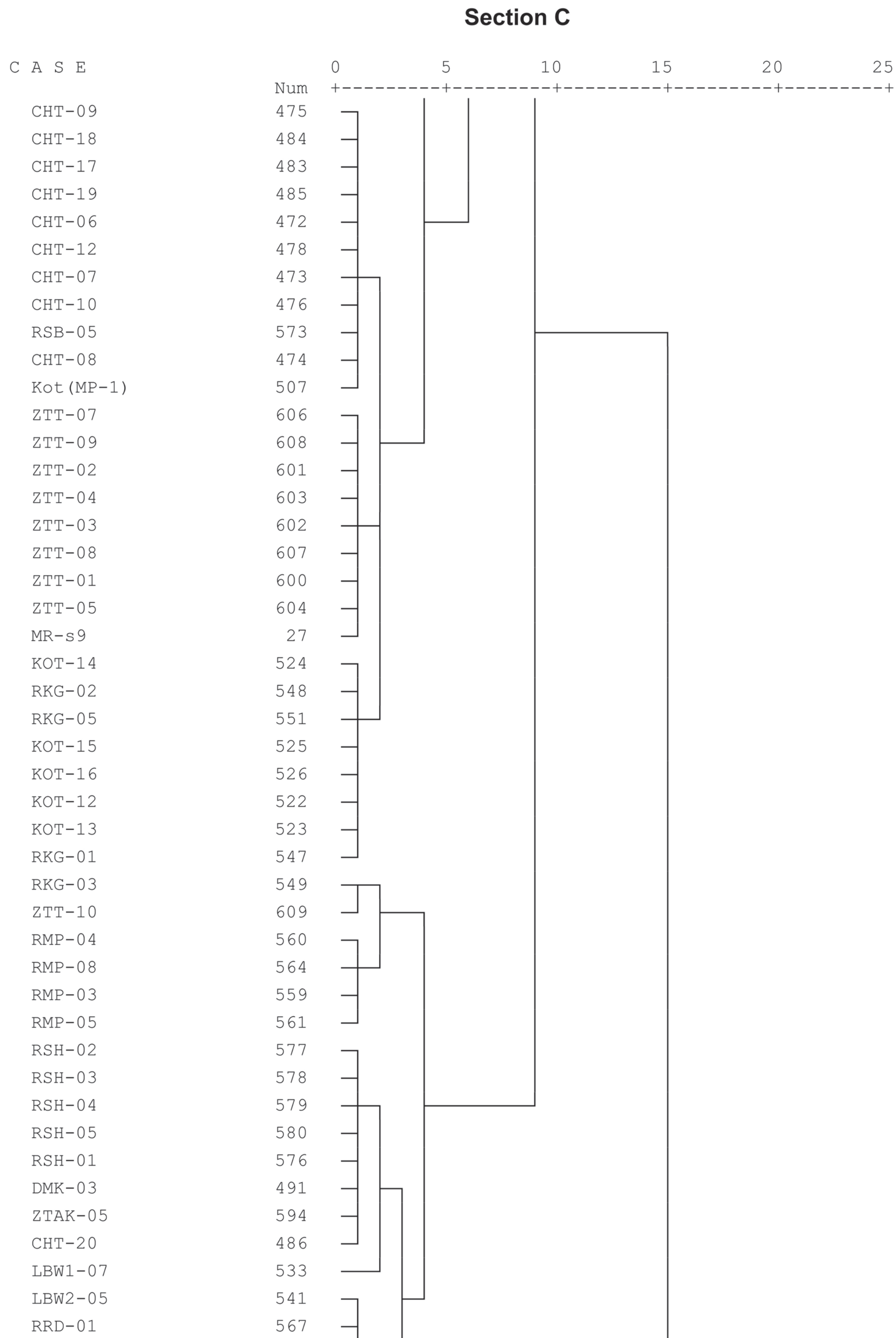
| Figure 7.48 | Function 1 | Function 2 |
|---|---|---|
| Log Al | .082 | .919 |
| Log Co | -.097 | -.316 |
| Log Cr | -.194 | -.547 |
| Log Eu | .136 | -.112 |
| Log Fe | .067 | 1.018 |
| Log La | -1.137 | -.183 |
| Log Mn | -.052 | -1.084 |
| Log Na | .201 | .108 |
| Log Sc | .884 | .414 |
| Log V | -.251 | -.746 |
| Log Zn | .383 | .820 |

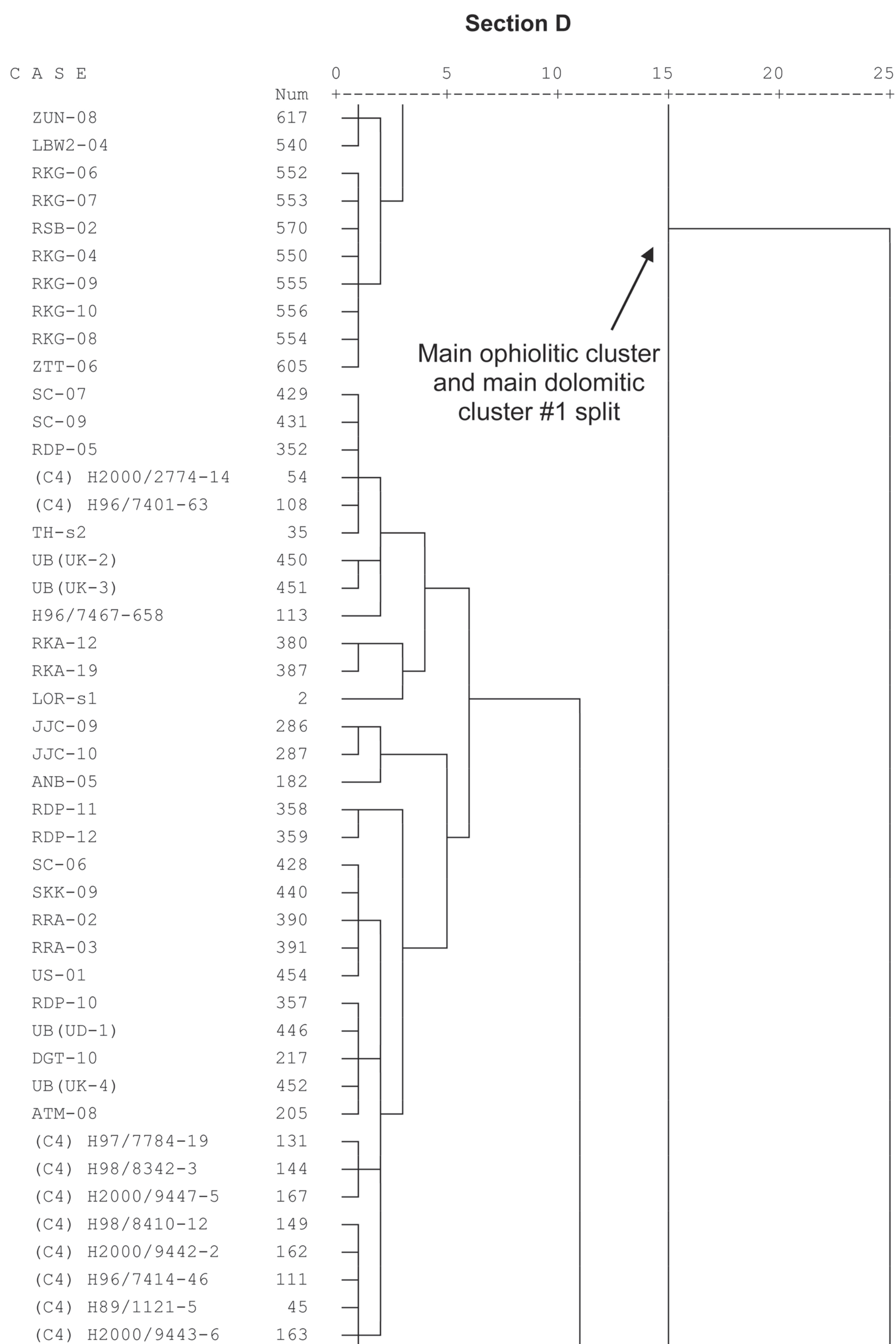
# APPENDIX 7.9

# CLUSTER ANALYSIS (COMPLETE LINKAGE) OF ALL STEATITE ARTIFACTS AND GEOLOGIC SAMPLES

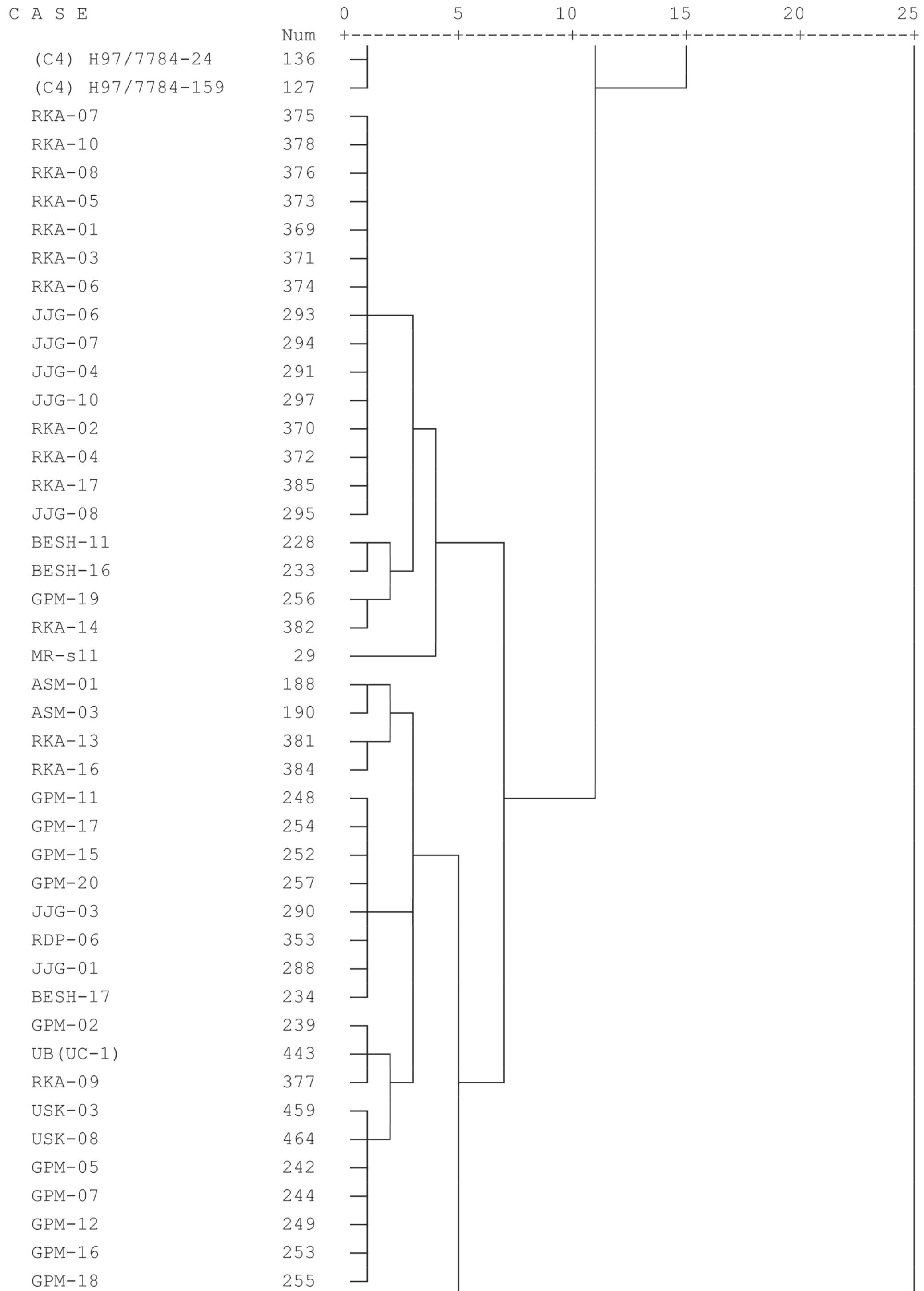



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CHT-13 479
CHT-14 480
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CHT-05 471
CHT-01 467
RMP-02 558
RMP-09 565
DMK-16 503
RMP-06 562
RMP-07 563
DMK-12 499
DMK-20 506
DMB-01 488
DMK-02 490
DMK-13 500
DMK-17 504
DMK-14 501
DMK-15 502
DMK-11 498
CHT-11 477
DMK-18 505
RMP-01 557
RMP-10 566
KOT-02 512
KOT-04 514
KOT-01 511
KOT-05 515
Kot(MP-2) 508
Kot(MP-3) 509
KOT-10 520
KOT-11 521
KOT-03 513
KOT-08 518
KOT-09 519
KOT-07 517
RST-03 582
RST-08 587
RRA-06 394
RRA-08 396
RST-10 589
LBW1-02 528
LBW1-04 530

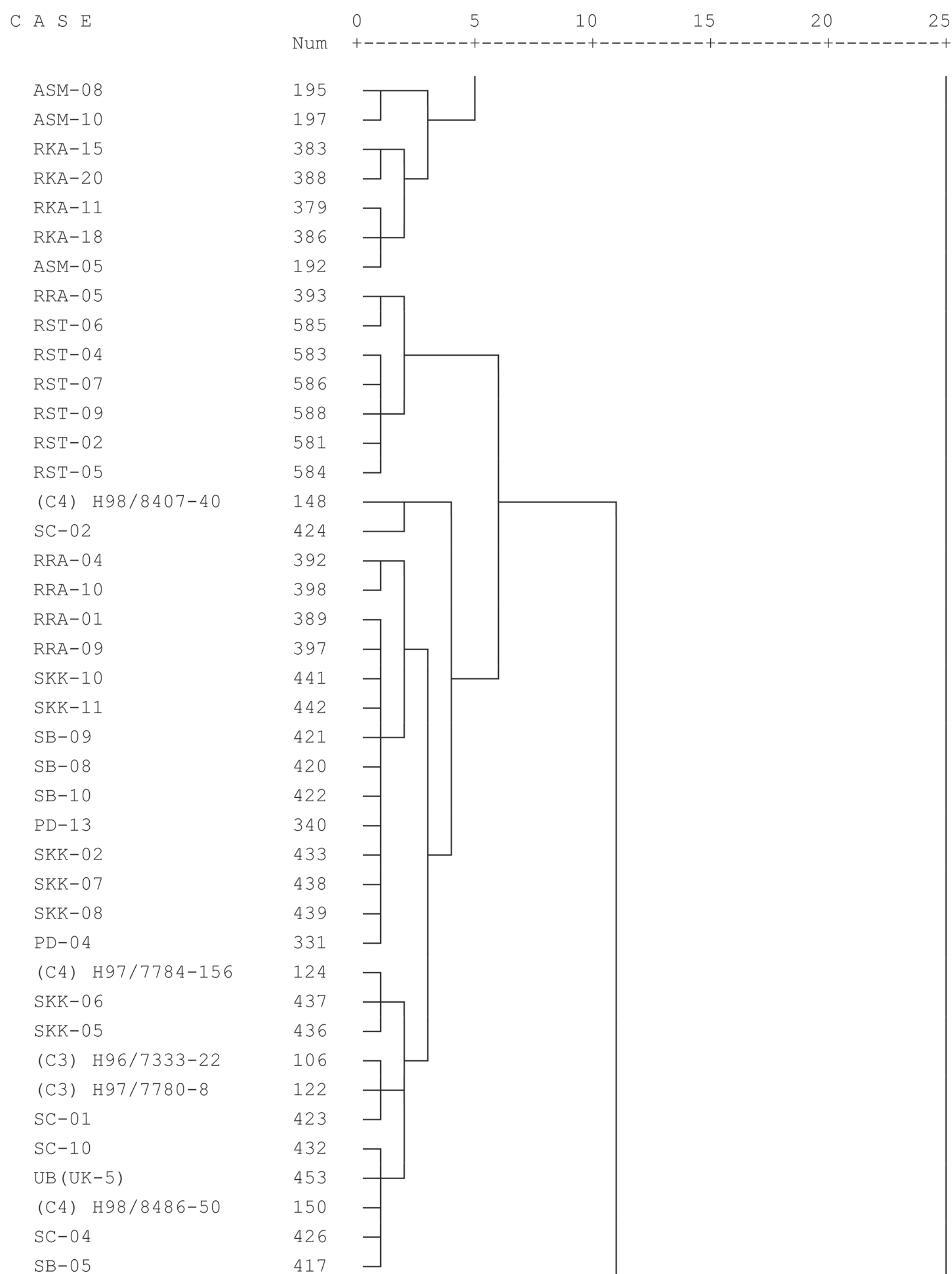

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CHT-12 478
CHT-07 473
CHT-10 476
RSB-05 573
CHT-08 474
Kot(MP-1) 507
ZTT-07 606
ZTT-09 608
ZTT-02 601
ZTT-04 603
ZTT-03 602
ZTT-08 607
ZTT-01 600
ZTT-05 604
MR-s9 27
KOT-14 524
RKG-02 548
RKG-05 551
KOT-15 525
KOT-16 526
KOT-12 522
KOT-13 523
RKG-01 547
RKG-03 549
ZTT-10 609
RMP-04 560
RMP-08 564
RMP-03 559
RMP-05 561
RSH-02 577
RSH-03 578
RSH-04 579
RSH-05 580
RSH-01 576
DMK-03 491
ZTAK-05 594
CHT-20 486
LBW1-07 533
LBW2-05 541
RRD-01 567


Section D
CASE
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ZUN-08 617
LBW2-04 540
RKG-06 552
RKG-07 553
RSB-02 570
RKG-04 550
RKG-09 555
RKG-10 556
RKG-08 554
ZTT-06 605
SC-07 429
SC-09 431
RDP-05 352
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(C4) H96/7401-63 108
TH-s2 35
UB(UK-2) 450
UB(UK-3) 451
H96/7467-658 113
RKA-12 380
RKA-19 387
LOR-s1 2
JJC-09 286
JJC-10 287
ANB-05 182
RDP-11 358
RDP-12 359
SC-06 428
SKK-09 440
RRA-02 390
RRA-03 391
US-01 454
RDP-10 357
UB(UD-1) 446
DGT-10 217
UB(UK-4) 452
ATM-08 205
(C4) H97/7784-19 131
(C4) H98/8342-3 144
(C4) H2000/9447-5 167
(C4) H98/8410-12 149
(C4) H2000/9442-2 162
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(C4) H89/1121-5 45
(C4) H2000/9443-6 163
Main ophiolitic cluster and main dolomitic cluster #1 split

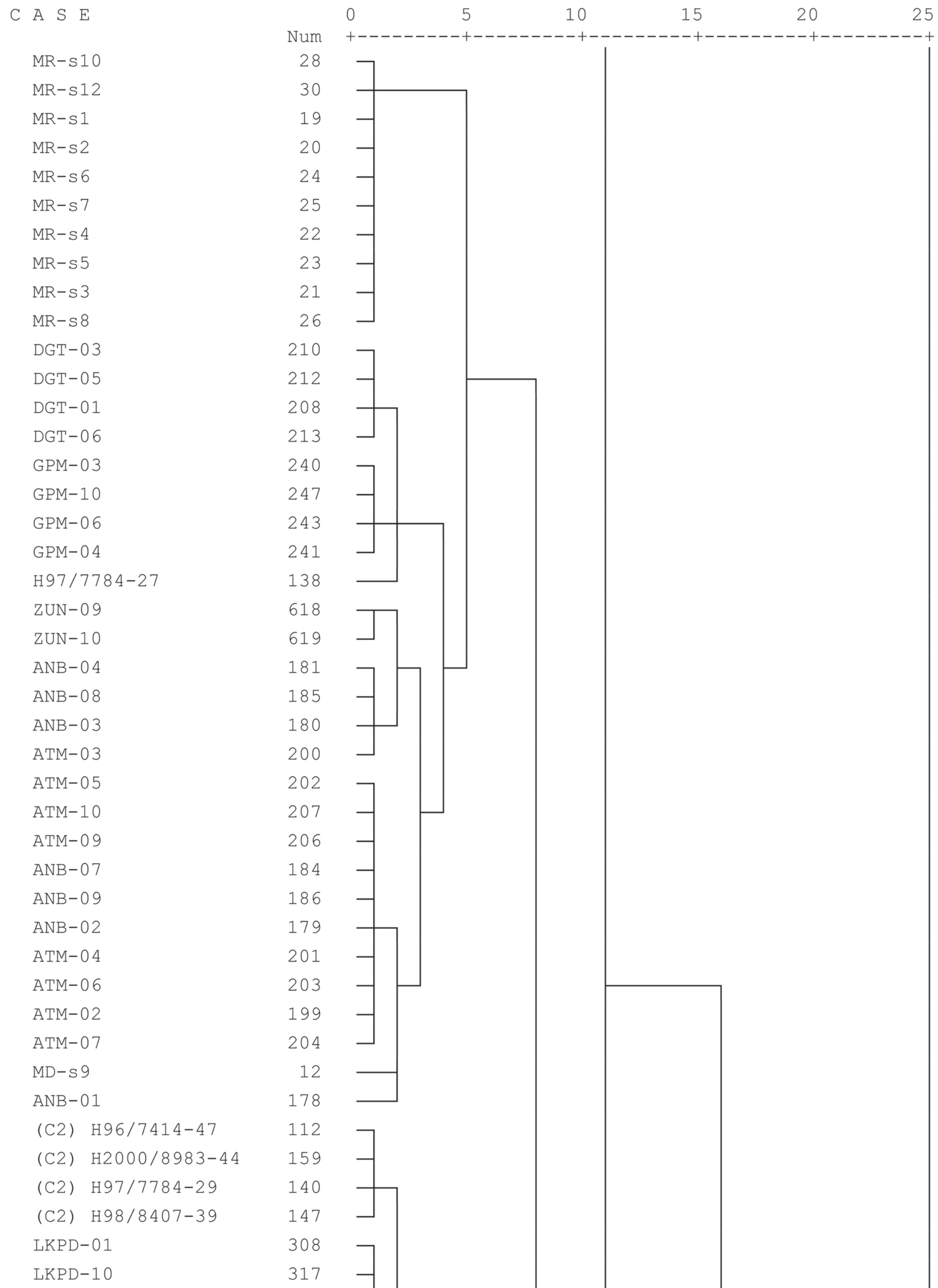
## Section E


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RKA-10 378
RKA-08 376
RKA-05 373
RKA-01 369
RKA-03 371
RKA-06 374
JJG-06 293
JJG-07 294
JJG-04 291
JJG-10 297
RKA-02 370
RKA-04 372
RKA-17 385
JJG-08 295
BESH-11 228
BESH-16 233
GPM-19 256
RKA-14 382
MR-s11 29
ASM-01 188
ASM-03 190
RKA-13 381
RKA-16 384
GPM-11 248
GPM-17 254
GPM-15 252
GPM-20 257
JJG-03 290
RDP-06 353
JJG-01 288
BESH-17 234
GPM-02 239
UB(UC-1) 443
RKA-09 377
USK-03 459
USK-08 464
GPM-05 242
GPM-07 244
GPM-12 249
GPM-16 253
GPM-18 255

## Section F


C A S E
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ASM-08 195
ASM-10 197
RKA-15 383
RKA-20 388
RKA-11 379
RKA-18 386
ASM-05 192
RRA-05 393
RST-06 585
RST-04 583
RST-07 586
RST-09 588
RST-02 581
RST-05 584
(C4) H98/8407-40 148
SC-02 424
RRA-04 392
RRA-10 398
RRA-01 389
RRA-09 397
SKK-10 441
SKK-11 442
SB-09 421
SB-08 420
SB-10 422
PD-13 340
SKK-02 433
SKK-07 438
SKK-08 439
PD-04 331
(C4) H97/7784-156 124
SKK-06 437
SKK-05 436
(C3) H96/7333-22 106
(C3) H97/7780-8 122
SC-01 423
SC-10 432
UB(UK-5) 453
(C4) H98/8486-50 150
SC-04 426
SB-05 417

## Section G



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MR-s10 28
MR-s12 30
MR-s1 19
MR-s2 20
MR-s6 24
MR-s7 25
MR-s4 22
MR-s5 23
MR-s3 21
MR-s8 26
DGT-03 210
DGT-05 212
DGT-01 208
DGT-06 213
GPM-03 240
GPM-10 247
GPM-06 243
GPM-04 241
H97/7784-27 138
ZUN-09 618
ZUN-10 619
ANB-04 181
ANB-08 185
ANB-03 180
ATM-03 200
ATM-05 202
ATM-10 207
ATM-09 206
ANB-07 184
ANB-09 186
ANB-02 179
ATM-04 201
ATM-06 203
ATM-02 199
ATM-07 204
MD-s9 12
ANB-01 178
(C2) H96/7414-47 112
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LKPD-10 317

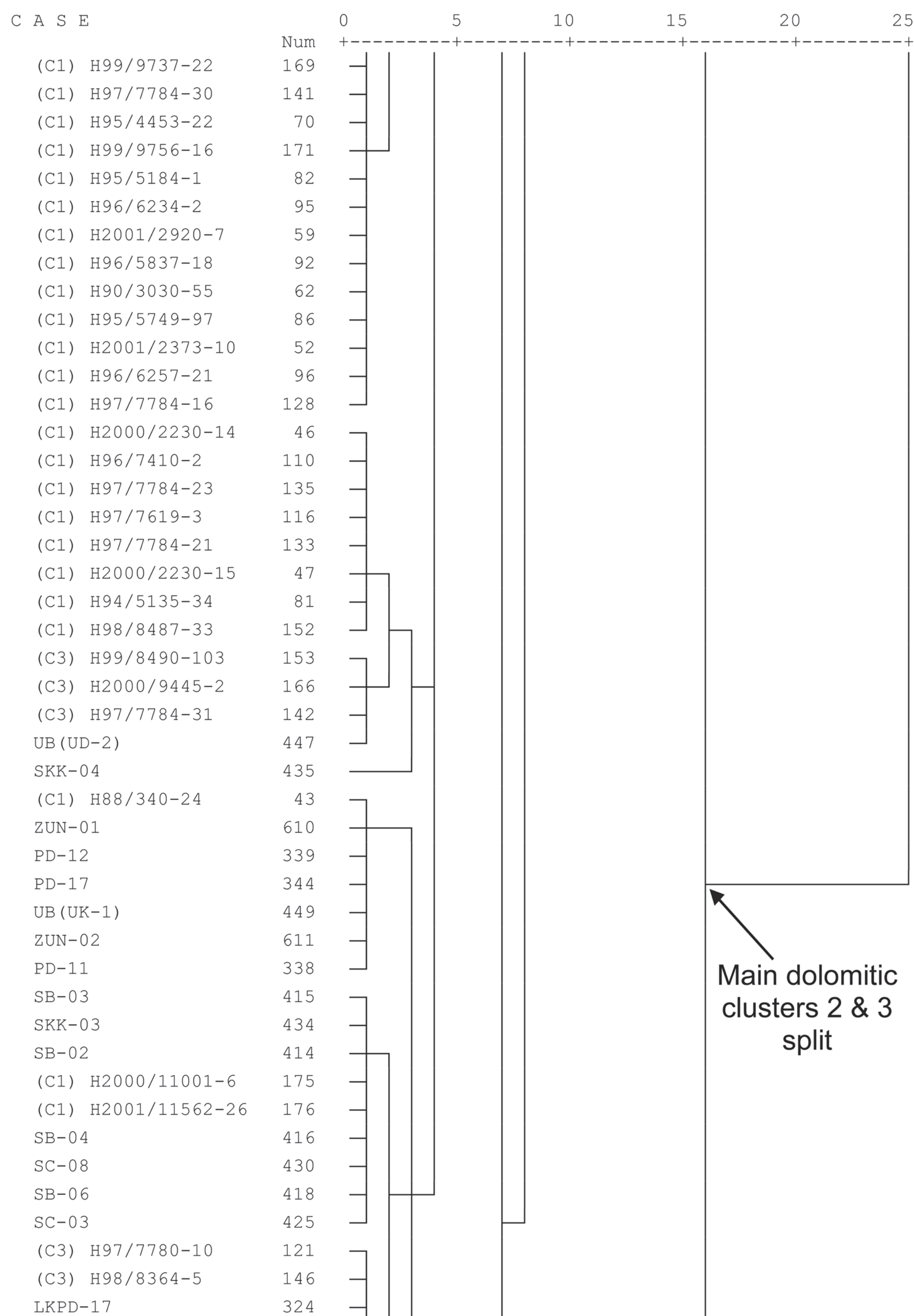
## Section H

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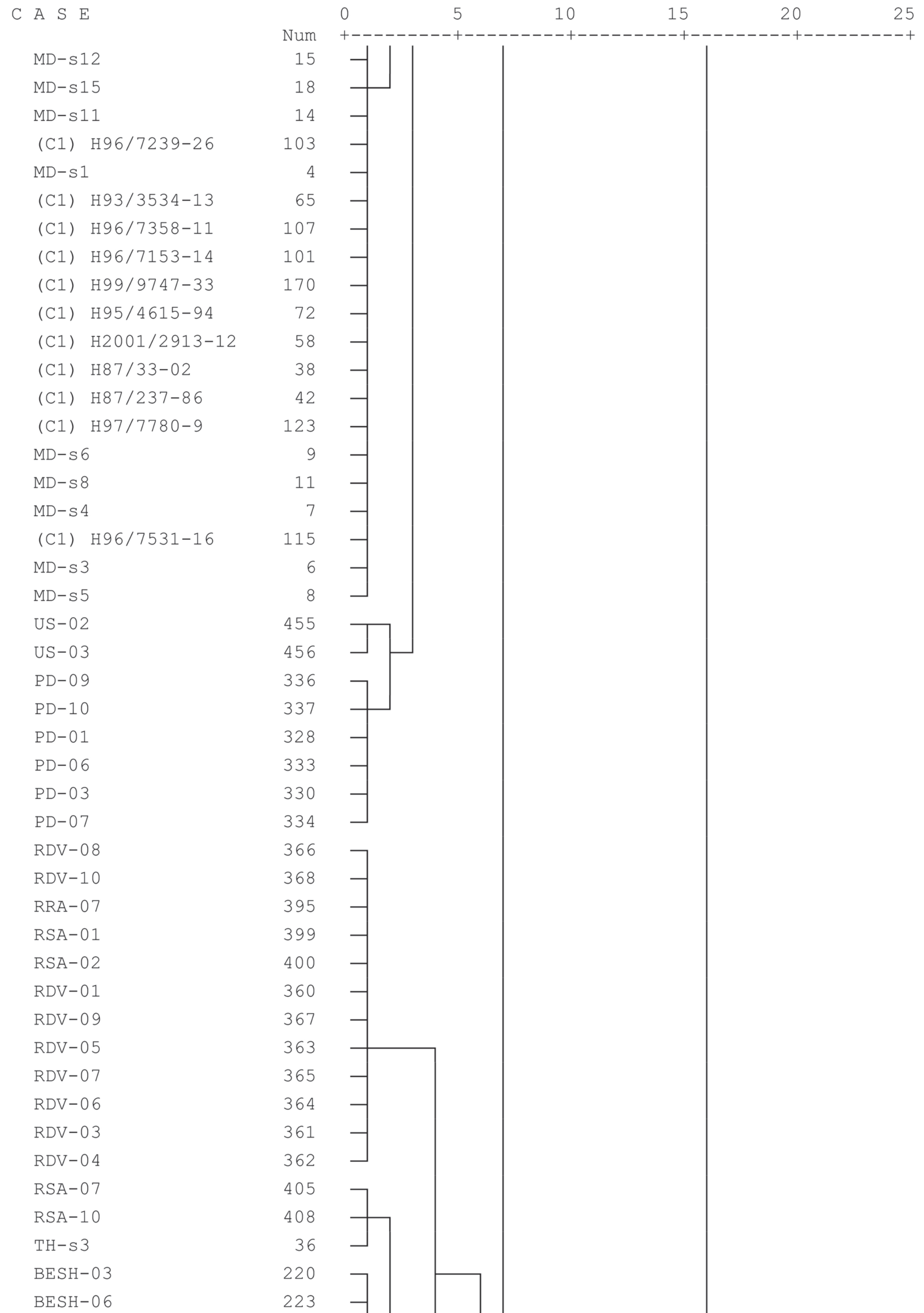
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| (C2) H2000/9973-13 | 174 |
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| RSA-14 | 412 |
| JAMPT-03 | 260 |
| JAMPT-20 | 277 |
| JAMPT-01 | 258 |
| (C1) H2000/2880-16 | 57 |
| (C1) H95/6509-97 | 97 |
| (C1) H95/4751-8 | 76 |
| (C1) H96/7467-790 | 114 |
| TH-s5 | 37 |
| (C2) H95/4613-42 | 71 |
| (C2) H96/7105-8 | 98 |
| (C2) H2000/2230-16 | 48 |
| (C2) H2000/8992-1 | 160 |
| (C2) H2000/2301-176 | 50 |
| (C2) H2000/2301-177 | 51 |
| (C2) H97/7784-22 | 134 |
| (C2) H97/7784-28 | 139 |
| (C2) H99/8492-229 | 154 |
| (C2) H96/7410-1 | 109 |
| (C2) H99/8956-1 | 158 |
| (C2) H97/7784-18 | 130 |
| (C2) H97/7784-20 | 132 |
| (C2) H2000/2230-17 | 49 |
| (C2) H98/8487-32 | 151 |
| (C2) H2000/8997-4 | 161 |
| (C2) H97/7784-17 | 129 |
| (C2) H97/7784-25 | 137 |
| (C2) H2000/9443-7 | 164 |
| PD-14 | 341 |
| PD-19 | 346 |
| PD-20 | 347 |
| UB(UC-2) | 444 |
| (C1) H99/7649-42 | 120 |
| (C1) H99/9779-4 | 172 |
| (C1) H93/3710-16 | 66 |
| (C1) H96/7156-14 | 102 |
| (C1) H95/5713-145 | 83 |
| (C1) H90/3068-50 | 63 |
| (C1) H95/5734-31 | 84 |
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| (C1) H2001/2922-6 | 60 |
| (C1) H93/3869-24 | 69 |

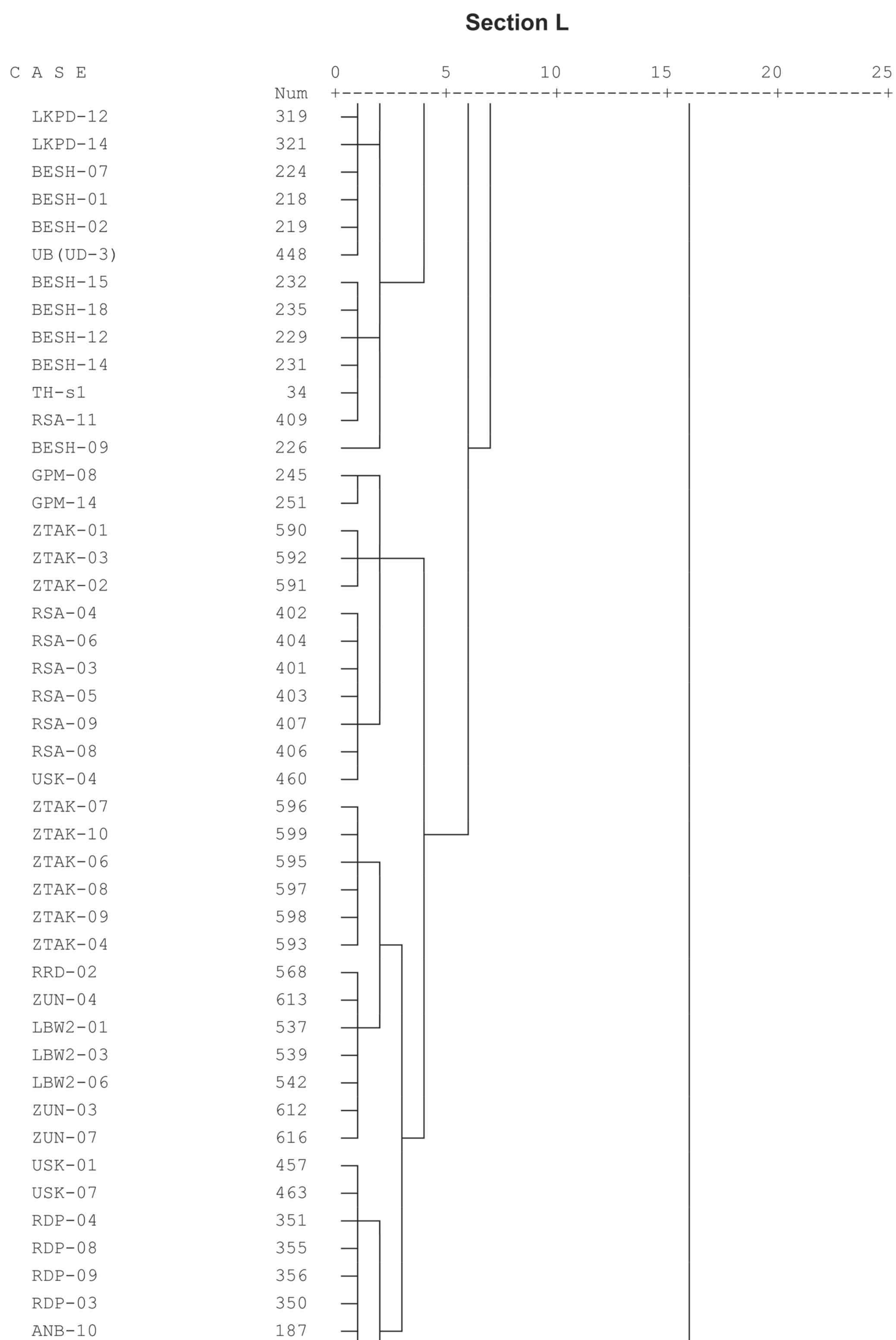
## Section I

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  MD-s14                           17
  (C1) H96/7257-46                105
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  (C1) H96/6219-44                 94
  (C1) H95/4950-4                  78
  (C1) H95/4961-176                80
  (C1) H95/4954-18                 79
  (C1) H2000/2774-15               55
  (C1) H2001/11923-9              177
  (C1) H2000/9514-93              168
  (C1) H2000/2789-30               56
  (C1) H96/7256-43                104
  (C1) H96/6218-8                  93
  MD-s7                            10
  (C1) H89/1018-13                 44
  PD-05                           332
  PD-18                           345
  PD-08                           335
  PD-15                           342
  PD-16                           343
  JAMPT-05                        262
  JAMPT-08                        265
  JAMPT-04                        261
  JAMPT-18                        275
  JAMPT-19                        276
  JAMPT-06                        263
  JAMPT-15                        272
  JAMPT-12                        269
  JAMPT-17                        274
  JAMPT-14                        271
  JAMPT-11                        268
  JAMPT-13                        270
  JAMPT-07                        264
  JAMPT-10                        267
  JAMPT-09                        266
  JAMPT-16                        273
  (C1) H90/3290-17                 64
  (C1) H98/8355-2                 145
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  (C1) H95/4746-7                  75
  (C1) H95/5820-11a                91
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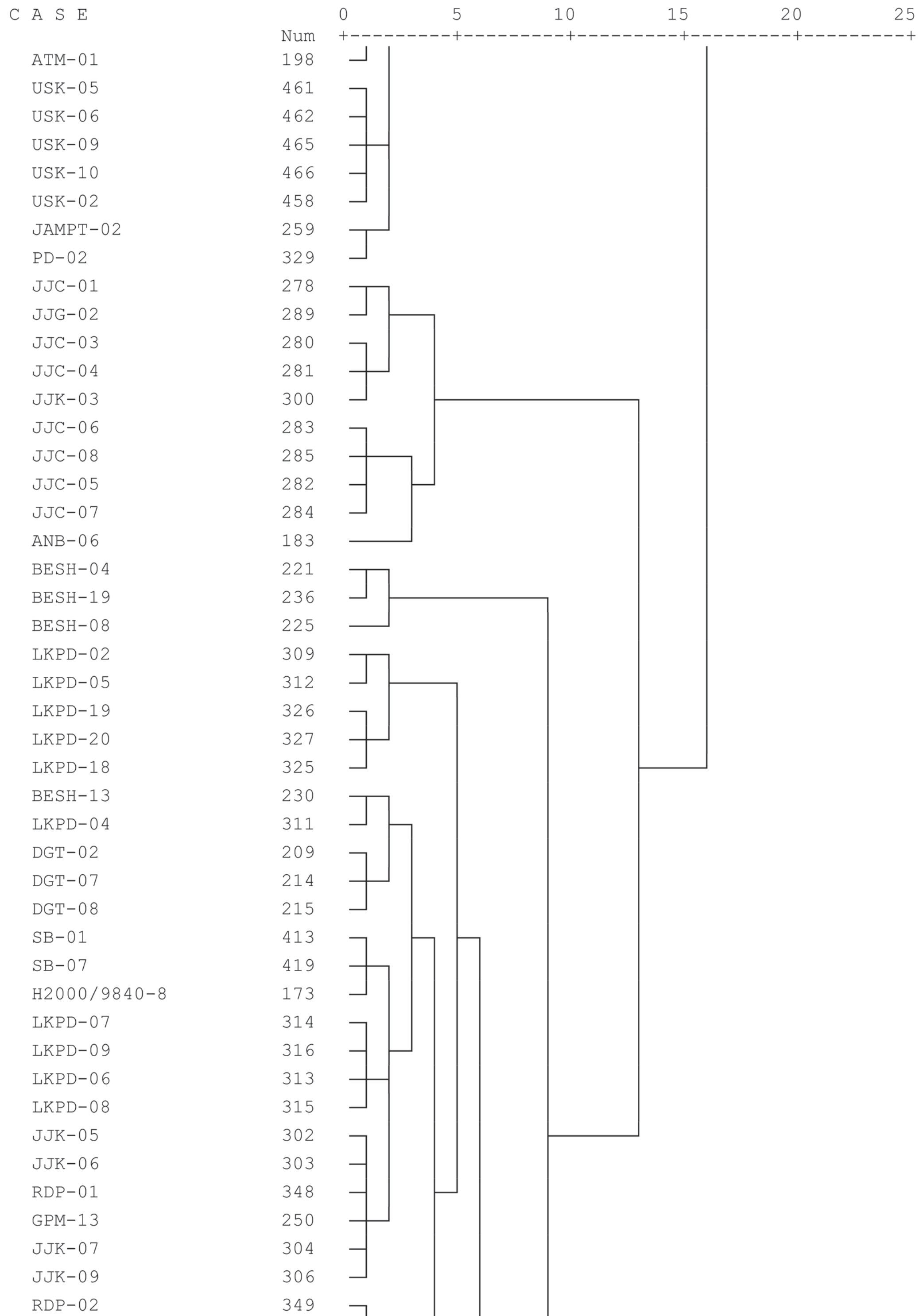

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(C1) H96/6234-2 95
(C1) H2001/2920-7 59
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(C1) H2001/2373-10 52
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(C1) H2000/2230-14 46
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(C3) H97/7784-31 142
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SKK-04 435
(C1) H88/340-24 43
ZUN-01 610
PD-12 339
PD-17 344
UB(UK-1) 449
ZUN-02 611
PD-11 338
SB-03 415
SKK-03 434
SB-02 414
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(C1) H2001/11562-26 176
SB-04 416
SC-08 430
SB-06 418
SC-03 425
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(C3) H98/8364-5 146
LKPD-17 324
Main dolomitic clusters 2 & 3 split

## Section K

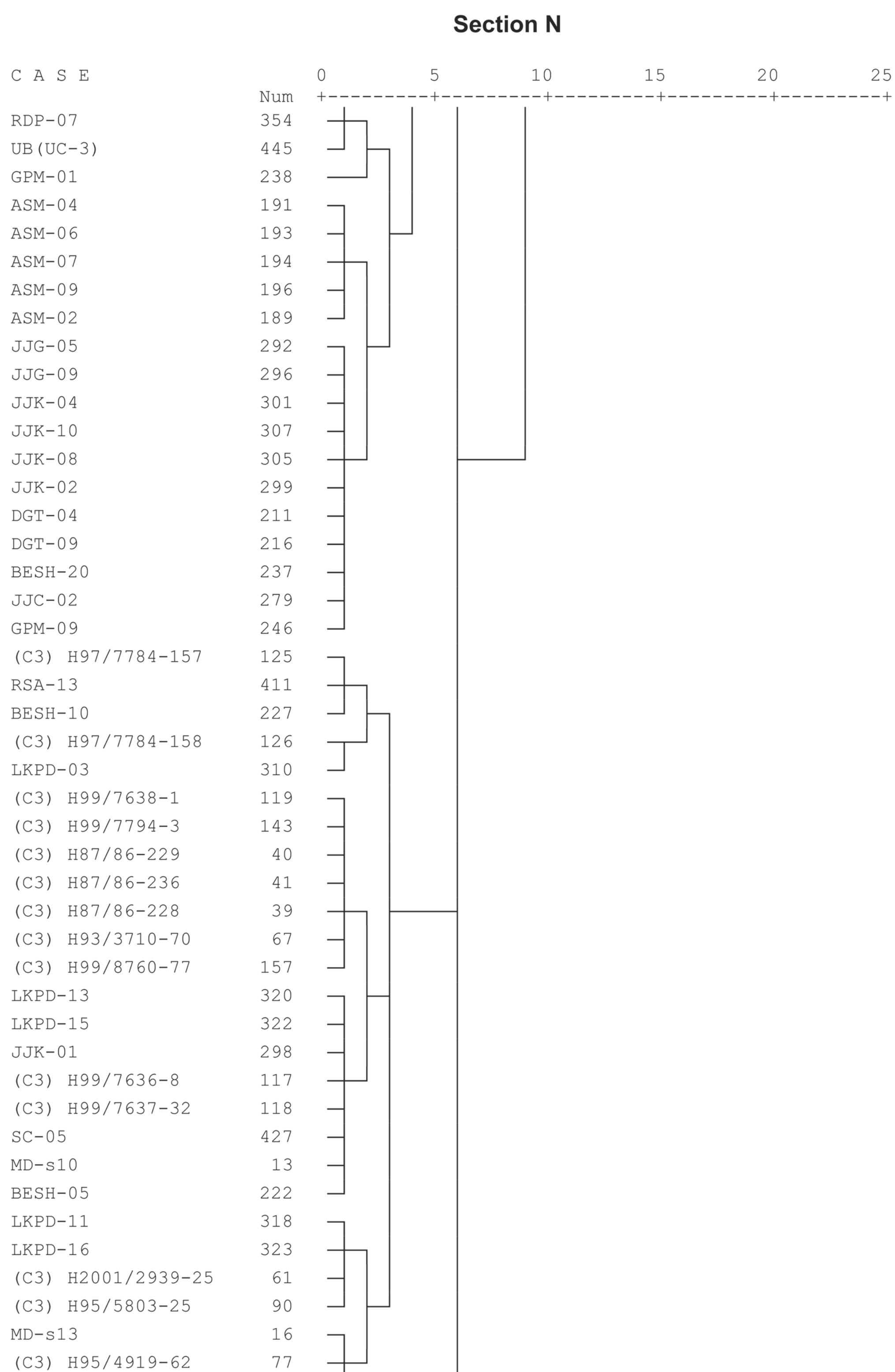

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MD-s15 18
MD-s11 14
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(C1) H96/7358-11 107
(C1) H96/7153-14 101
(C1) H99/9747-33 170
(C1) H95/4615-94 72
(C1) H2001/2913-12 58
(C1) H87/33-02 38
(C1) H87/237-86 42
(C1) H97/7780-9 123
MD-s6 9
MD-s8 11
MD-s4 7
(C1) H96/7531-16 115
MD-s3 6
MD-s5 8
US-02 455
US-03 456
PD-09 336
PD-10 337
PD-01 328
PD-06 333
PD-03 330
PD-07 334
RDV-08 366
RDV-10 368
RRA-07 395
RSA-01 399
RSA-02 400
RDV-01 360
RDV-09 367
RDV-05 363
RDV-07 365
RDV-06 364
RDV-03 361
RDV-04 362
RSA-07 405
RSA-10 408
TH-s3 36
BESH-03 220
BESH-06 223


Section L
C A S E
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LKPD-14 321
BESH-07 224
BESH-01 218
BESH-02 219
UB(UD-3) 448
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BESH-18 235
BESH-12 229
BESH-14 231
TH-s1 34
RSA-11 409
BESH-09 226
GPM-08 245
GPM-14 251
ZTAK-01 590
ZTAK-03 592
ZTAK-02 591
RSA-04 402
RSA-06 404
RSA-03 401
RSA-05 403
RSA-09 407
RSA-08 406
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ZTAK-04 593
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ZUN-04 613
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LBW2-03 539
LBW2-06 542
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ZUN-07 616
USK-01 457
USK-07 463
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RDP-08 355
RDP-09 356
RDP-03 350
ANB-10 187

## Section M


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USK-10 466
USK-02 458
JAMPT-02 259
PD-02 329
JJC-01 278
JJG-02 289
JJC-03 280
JJC-04 281
JJK-03 300
JJC-06 283
JJC-08 285
JJC-05 282
JJC-07 284
ANB-06 183
BESH-04 221
BESH-19 236
BESH-08 225
LKPD-02 309
LKPD-05 312
LKPD-19 326
LKPD-20 327
LKPD-18 325
BESH-13 230
LKPD-04 311
DGT-02 209
DGT-07 214
DGT-08 215
SB-01 413
SB-07 419
H2000/9840-8 173
LKPD-07 314
LKPD-09 316
LKPD-06 313
LKPD-08 315
JJK-05 302
JJK-06 303
RDP-01 348
GPM-13 250
JJK-07 304
JJK-09 306
RDP-02 349

## Section N


C A S E
Num
0 5 10 15 20 25
RDP-07 354
UB(UC-3) 445
GPM-01 238
ASM-04 191
ASM-06 193
ASM-07 194
ASM-09 196
ASM-02 189
JJG-05 292
JJG-09 296
JJK-04 301
JJK-10 307
JJK-08 305
JJK-02 299
DGT-04 211
DGT-09 216
BESH-20 237
JJC-02 279
GPM-09 246
(C3) H97/7784-157 125
RSA-13 411
BESH-10 227
(C3) H97/7784-158 126
LKPD-03 310
(C3) H99/7638-1 119
(C3) H99/7794-3 143
(C3) H87/86-229 40
(C3) H87/86-236 41
(C3) H87/86-228 39
(C3) H93/3710-70 67
(C3) H99/8760-77 157
LKPD-13 320
LKPD-15 322
JJK-01 298
(C3) H99/7636-8 117
(C3) H99/7637-32 118
SC-05 427
MD-s10 13
BESH-05 222
LKPD-11 318
LKPD-16 323
(C3) H2001/2939-25 61
(C3) H95/5803-25 90
MD-s13 16
(C3) H95/4919-62 77

## Section O

```
C A S E                     0         5        10        15        20        25
                       Num  +---------+---------+---------+---------+---------+

  (C3) H96/7106-27      99   ─┐
  (C3) H96/7118-9      100   ─┤
  (C3) H95/4723-2       73   ─┤
  (C3) H99/8497-3      155   ─┘
  H2000/9445-1         165   ───────────
```

# APPENDIX 7.10

# CLUSTER ANALYSIS (COMPLETE LINKAGE) OF 140 STEATITE ARTIFACTS FROM HARAPPA

## Section A

| Artifact # | Period | Mound | Trench | 1st / 2nd PGM | Type |
|---|---|---|---|---|---|
| H2000/2753-17 | 3C | E | Tr.55 | PD / SB | E |
| H96/6219-44 | S&D | ET | Tr.35 | SB / SKK | D |
| H95/4950-4 | 3C | ET | Tr.28 | SKK / SB | A |
| H95/4961-176 | 3C | ET | Tr.28 | SKK / SB | A |
| H95/4954-18 | 3C | ET | Tr.28 | SKK / SB | E |
| H2000/2774-15 | 3C | E | Tr.55 | SKK / PD | C |
| H2001/11923-9 | 3C | E | Tr.11 | SB / SKK | C |
| H2000/9514-93 | 2 | AB | Tr.39 | SB / JAMPT | E |
| H2000/2789-30 | 3C | E | Tr.55 | SKK / SB | C |
| H96/7256-43 | 3B | F | Tr.37 | SKK / SB | B |
| H96/6218-8 | S&D | ET | Tr.35 | SKK / SB | C |
| H96/7239-26 | 3C | F | Tr.37 | SB / SC | A |
| H2001/11562-26 | S&D | E | Tr.11 | SB / SC | F |
| H96/7531-16 | 1 | AB | Tr.39 | ATM / SKK | A |
| H96/7257-46 | 3B | F | Tr.37 | PD / SKK | B |
| H90/3290-17 | S&D | E | Tr.59 | SB / SKK | D |
| H98/8355-2 | 3B | AB | Tr.39 | SKK / SB | A |
| H93/3808-52 | S&D | E | Tr.5 | SKK / SB | A |
| H95/4746-7 | 3C | ET | Tr.19 | SB / SKK | A |
| H95/5820-11a | 3C | ET | Tr.28 | PD / SKK | A |
| H99/9737-22 | 3C | F | Tr.43 | SKK / SB | A |
| H97/7784-30 | 3A | AB | Tr.42 | SKK / SB | E |
| H95/4453-22 | S&D | E | Tr.11 | SB / SKK | D |
| H99/9756-16 | 3C | F | Tr.43 | SB / SKK | A |
| H95/5184-1 | 3C | E | Tr.7/8 | SB / SKK | A |
| H96/6234-2 | S&D | ET | Tr.35 | SB / SKK | C |
| H2001/2920-7 | S&D | E | Tr.57 | SKK / SB | C |
| H96/5837-18 | 3C | ET | Tr.28 | SB / LKPD | B |
| H90/3030-55 | S&D | E | Tr.58 | JAMPT / RSA | E |
| H95/5749-97 | 3C | ET | Tr.32 | SKK / SB | C |
| H2001/2373-10 | 3B | E | Tr.54 | SKK / SB | C |
| H96/6257-21 | 3C | ET | Tr.35 | SKK / SB | A |
| H97/7784-16 | 3A | AB | Tr.42 | RSA / SKK | A |
| H2000/2230-14 | 3B | E | Tr.54 | SB / LKPD | C |
| H96/7410-2 | 2/3 | AB | Tr.39 | SKK / SB | E |
| H97/7784-23 | 3A | AB | Tr.42 | SKK / SB | C |
| H97/7619-3 | 3C | F | Tr.41 | SB / LKPD | C |
| H97/7784-21 | 3A | AB | Tr.42 | SB / SKK | B |
| H2000/2230-15 | 3B | E | Tr.54 | LKPD / SB | C |
| H94/5135-34 | 3C | E | Tr.7/8 | SB / SC | E |
| H99/7649-42 | 3C | F | Tr.41 | SB / SKK | A |
| H99/9779-4 | 3C | F | Tr.43 | SB / LKPD | A |
| H93/3710-16 | 3C | E | Tr.3 | SB / SKK | F |
| H96/7156-14 | 3C | E | Tr.36 | SB / SKK | G |
| H95/5713-145 | S&D | ET | Tr.32 | SB / SKK | C |
| H90/3068-50 | S&D | E | Tr.58 | SB / SKK | A |
| H95/5734-31 | 3C | ET | Tr.32 | PD / SB | C |
| H95/5763-19 | 3C | ET | Tr.32 | SB / LKPD | A |
| H2001/2922-6 | S&D | E | Tr.57 | SB / SKK | A |
| H93/3869-24 | 3C | E | Tr.7 | SKK / PD | A |
| H95/5747-125 | 3C | ET | Tr.32 | SB / SKK | B |
| H95/5759-25 | 3C | ET | Tr.32 | SB / PD | E |
| H95/4726-101 | 3C | ET | Tr.19 | SB / SKK | A |
| H87/33-02 | 3C | CEM | CEM | SB / SKK | F |
| H87/237-86 | S&D | CEM | CEM | SB / SKK | F |
| H97/7780-9 | 3B | AB | Tr.42 | SB / SKK | A |
| H89/1018-13 | S&D | AB/E | Tr.53 | SKK / SB | D |
| H93/3534-13 | S&D | E | Tr.2 | LKPD / SB | F |
| H96/7358-11 | 5 | AB | Tr.38 | LKPD / SKK | A |
| H96/7153-14 | S&D | E | Tr.36 | SB / SKK | D |
| H99/9747-33 | 3C | F | Tr.43 | SKK / SB | B |
| H95/4615-94 | 3C | ET | Tr.10 | SKK / SB | A |
| H2001/2913-12 | 3B | E | Tr.57 | SKK / SB | E |
| H2000/2880-16 | 3C | E | Tr.55 | SKK / SB | D |
| H95/6509-97 | 2 | E/ET | Tr.11 | JAMPT / RSA | B |
| H95/4751-8 | 3C | ET | Tr.19 | SKK / SB | E |
| H96/7467-790 | S&D | AB | Tr.39 | SKK / SB | A |
| H2000/11001-6 | 1 | AB | Tr.39 | JAMPT / RSA | A |
| H88/340-24 | S&D | E | Op. 3 | PD / SB | F |
| H98/8487-33 | 2 | AB | Tr.39 | PD / SKK | A |

Dendrogram scale: 0 5 10 15 20

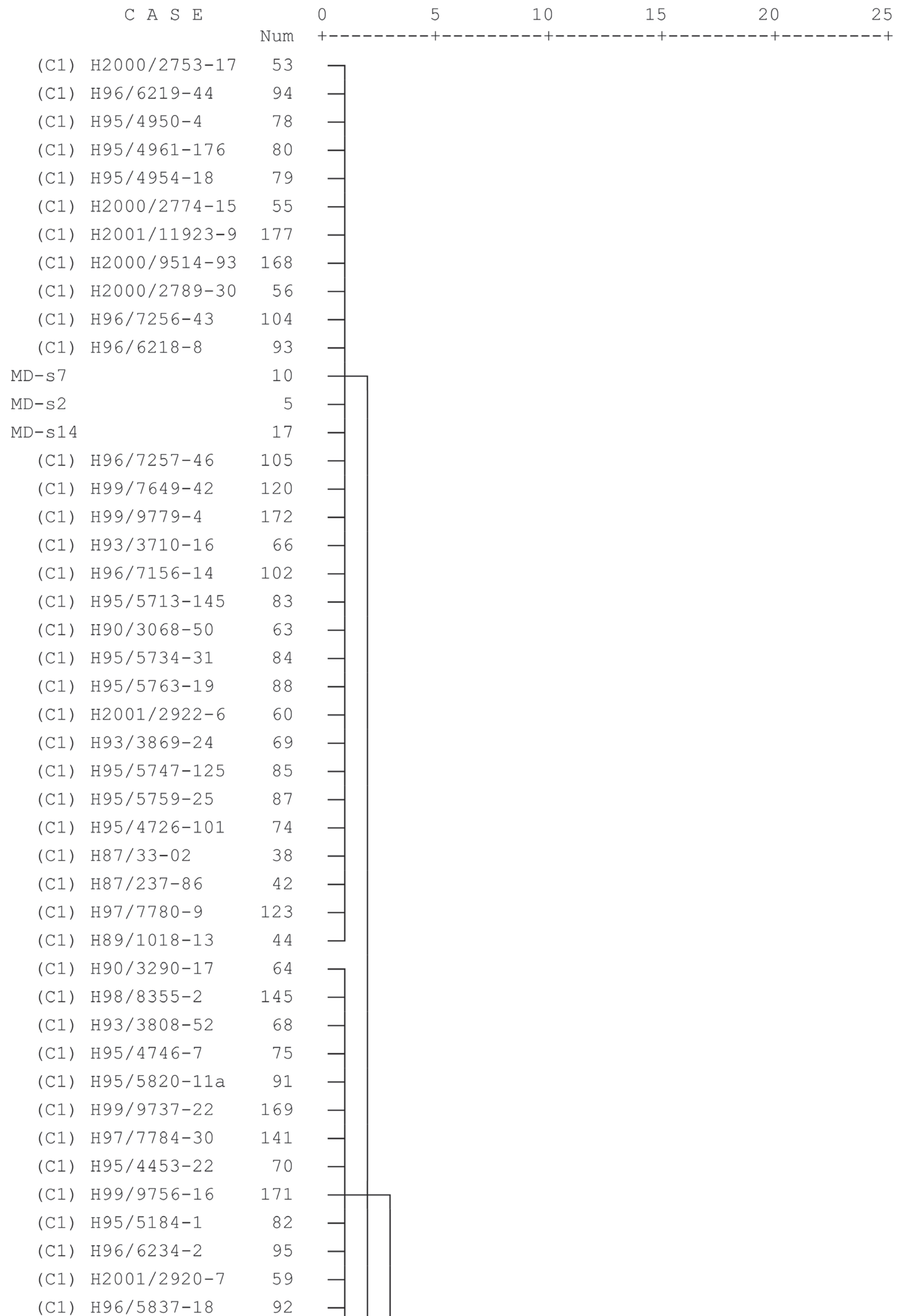
**Section B**

| | | | | | |
|---|---|---|---|---|---|
| H96/7414-47 | 2 | AB | Tr.39 | JAMPT / LKPD | A |
| H2000/8983-44 | 2 | AB | Tr.39 | SC / LKPD | E |
| H97/7784-29 | 3A | AB | Tr.42 | SC / SKK | B |
| H98/8407-39 | 2 | AB | Tr.39 | RDP / USK | E |
| H2000/9973-13 | 2 | AB | Tr.39 | JAMPT / RSA | C |
| H95/4613-42 | 3B | ET | Tr.10 | SKK / SB | A |
| H96/7105-8 | 3C | E | Tr.36 | SKK / SB | A |
| H2000/2230-16 | 3B | E | Tr.54 | JAMPT / RSA | C |
| H2000/8992-1 | 2 | AB | Tr.39 | JAMPT / RSA | E |
| H2000/2301-176 | 3A | E | Tr.54 | JAMPT / SB | B |
| H2000/2301-177 | 3A | E | Tr.54 | JAMPT / SB | B |
| H97/7784-22 | 3A | AB | Tr.42 | JAMPT / SKK | C |
| H97/7784-28 | 3A | AB | Tr.42 | SB / SKK | B |
| H99/8492-229 | 2 | AB | Tr.39 | SKK / SC | E |
| H96/7410-1 | 2/3A | AB | Tr.39 | SKK / SB | E |
| H99/8956-1 | 2 | AB | Tr.39 | SKK / JAMPT | A |
| H97/7784-18 | 3A | AB | Tr.42 | USK / SKK | A |
| H97/7784-20 | 3A | AB | Tr.42 | USK / SKK | A |
| H2000/2230-17 | 3B | E | Tr.54 | JAMPT / SKK | B |
| H98/8487-32 | 2 | AB | Tr.39 | JAMPT / SKK | E |
| H2000/8997-4 | 2 | AB | Tr.39 | JAMPT / SKK | A |
| H97/7784-17 | 3A | AB | Tr.42 | SKK / JAMPT | A |
| H97/7784-25 | 3A | AB | Tr.42 | SKK / JAMPT | A |
| H2000/9443-7 | 3B | AB | Tr.39 | JAMPT / USK | B |
| H99/7636-8 | 3C | F | Tr.41 | RSA / LKPD | E |
| H99/7637-32 | 3C | F | Tr.41 | LKPD / SB | G |
| H99/7638-1 | 3C | F | Tr.41 | SB / JAMPT | G |
| H99/7794-3 | 3C | AB | Tr.42 | SB / LKPD | B |
| H87/86-229 | 3C | CEM | CEM | SB / RSA | F |
| H87/86-236 | 3C | CEM | CEM | SB / LKPD | F |
| H87/86-228 | 3C | CEM | CEM | SB / SC | F |
| H93/3710-70 | 3C | E | Tr.3 | LKPD / SB | F |
| H99/8760-77 | 3C | F | Tr.43 | ANB /RSA | F |
| H95/5802-5 | 3C | ET | Tr.28 | LKPD / RSA | A |
| H97/7784-157 | 3A | AB | Tr.42 | LKPD / RSA | F |
| H97/7784-158 | 3A | AB | Tr.42 | LKPD / SB | A |
| H2001/2939-25 | 3B | E | Tr.57 | LKPD / RDP | G |
| H95/5803-25 | 3C | ET | Tr.28 | LKPD / RSA | B |
| H99/8490-103 | 2 | AB | Tr.39 | SC / SKK | B |
| H2000/9445-2 | 3B | AB | Tr.39 | SC / LKPD | G |
| H97/7784-31 | 3A | AB | Tr.42 | SC / LKPD | A |
| H96/7106-27 | 3C | E | Tr.36 | LKPD / RDP | G |
| H96/7118-9 | 3C | E | Tr.36 | LKPD / RDP | A |
| H95/4723-2 | 3C | ET | Tr.19 | LKPD / RDP | B |
| H99/8497-3 | 2 | AB | Tr.39 | LKPD / SC | E |
| H95/4919-62 | 3C | ET | Tr.28 | RDP / SC | D |
| H97/7780-10 | 3B | AB | Tr.42 | SB / SC | E |
| H98/8364-5 | 3B | AB | Tr.39 | SB / SC | F |
| H96/7333-22 | 5 | AB | Tr.38 | SC / SKK | A |
| H97/7780-8 | 3B | AB | Tr.42 | SC / SB | A |
| H2000/9445-1 | 3B | AB | Tr.39 | ANB / ATM | G |
| H97/7784-156 | 3A | AB | Tr.42 | SKK / SC | A |
| H98/8407-40 | 2 | AB | Tr.39 | SC / SKK | A |
| H98/8486-50 | 2 | AB | Tr.39 | SKK / SC | A |
| H98/8410-12 | 2 | AB | Tr.39 | SC / SKK | A |
| H2000/9442-2 | 3B | AB | Tr.39 | SC / SKK | E |
| H96/7414-46 | 2 | AB | Tr.39 | SC / SKK | A |
| H89/1121-5 | S&D | E | Tr.52 | SKK / SC | A |
| H2000/9443-6 | 3B | AB | Tr.39 | SKK / SC | A |
| H97/7784-24 | 3A | AB | Tr.42 | SKK / SC | C |
| H97/7784-159 | 3A | AB | Tr.42 | SKK / SC | A |
| H2000/2774-14 | 3C | E | Tr.55 | SC / RDP | G |
| H96/7401-63 | S&D | AB | Tr.39 | SC / RDP | F |
| H97/7784-19 | 3A | AB | Tr.42 | SC / SKK | A |
| H98/8342-3 | 3C | AB | Tr.39 | SC / SKK | F |
| H2000/9447-5 | 3B | AB | Tr.39 | SC / SKK | A |
| H97/7784-27 | 3A | AB | Tr.42 | LBW1 / LBW2 | A |
| H2000/9840-8 | 3C | F | Tr.43 | SB / SC | E |
| H98/8668-2 | 3C | F | Tr.43 | KOT / ZTT | E |
| H96/7467-658 | S&D | AB | Tr.39 | ATM / SC | A |

# APPENDIX 7.11

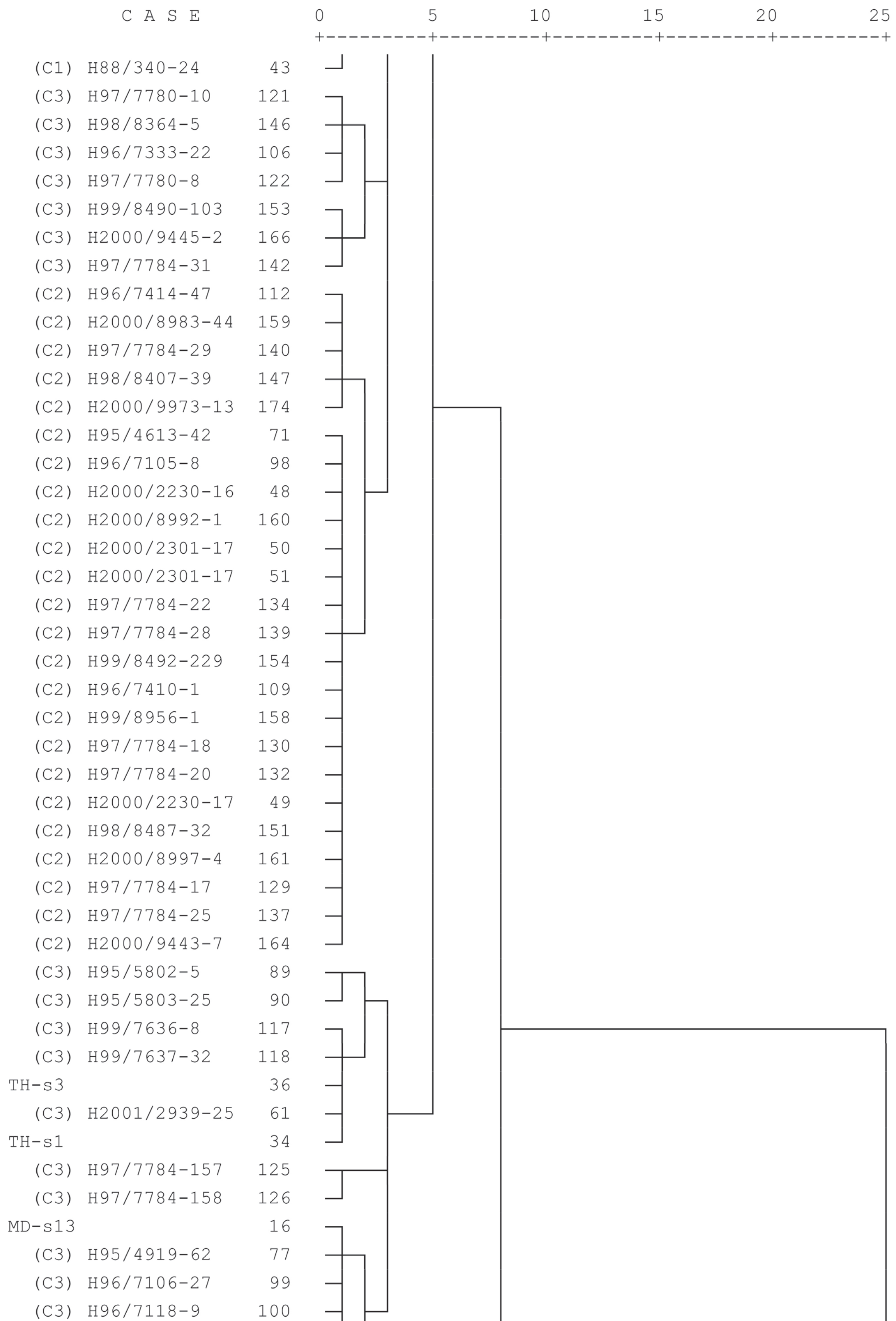
# CLUSTER ANALYSIS (COMPLETE LINKAGE) OF ALL 177 STEATITE ARTIFACTS

## Section A

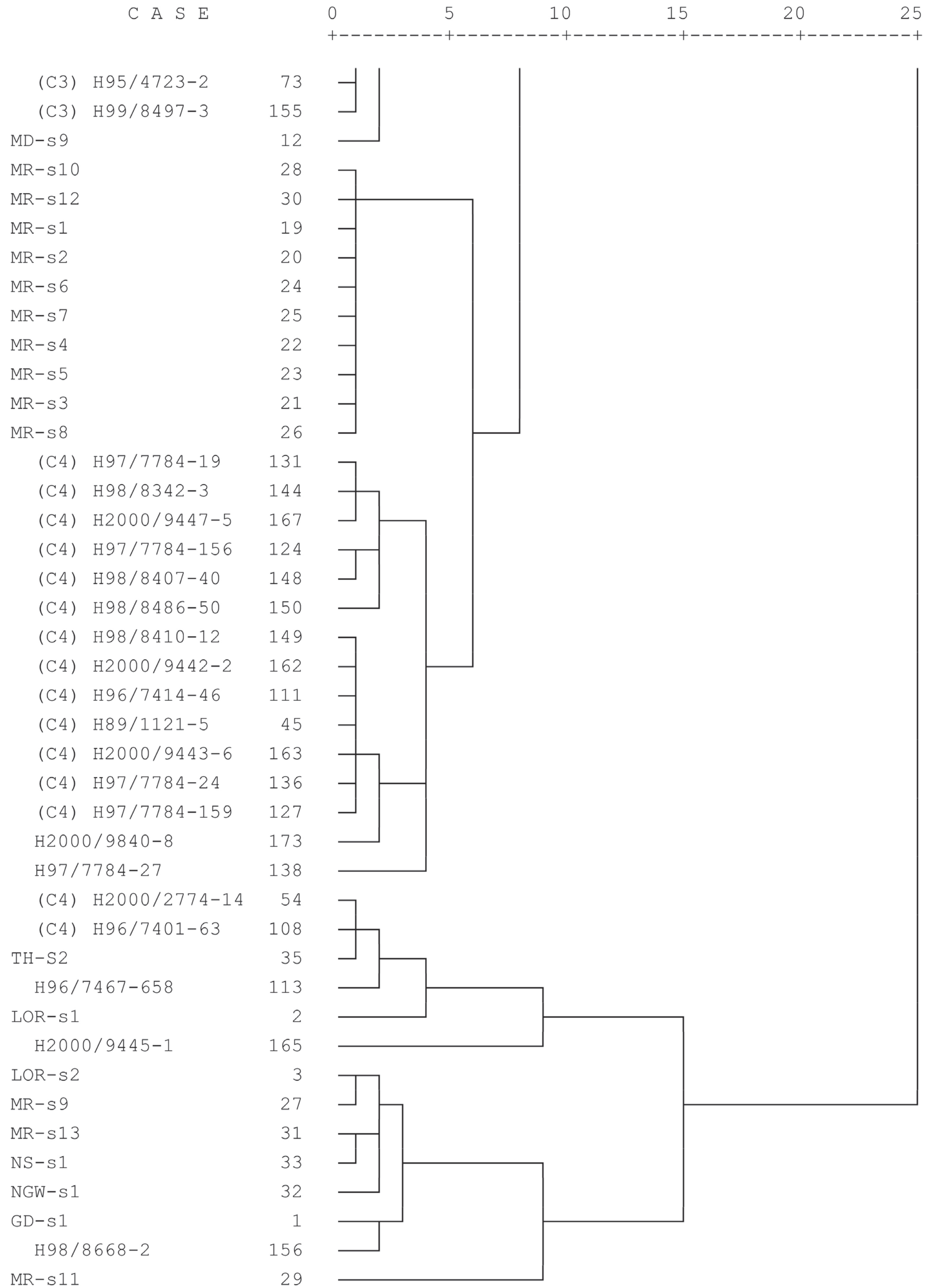


## Section B

```
        C A S E              0         5        10        15        20        25
                             +---------+---------+---------+---------+---------+
  (C1) H90/3030-55     62
  (C1) H95/5749-97     86
  (C1) H2001/2373-10   52
  (C1) H96/6257-21     96
  (C1) H97/7784-16    128
  (C1) H2000/2230-14   46
  (C1) H96/7410-2     110
  (C1) H97/7784-23    135
  (C1) H97/7619-3     116
  (C1) H97/7784-21    133
  (C1) H2000/2230-15   47
  (C1) H94/5135-34     81
  (C1) H98/8487-33    152
  (C1) H2000/2880-16   57
  (C1) H95/6509-97     97
  (C1) H95/4751-8      76
  (C1) H96/7467-790   114
TH-s5                  37
  (C1) H93/3534-13     65
  (C1) H96/7358-11    107
  (C1) H96/7153-14    101
  (C1) H99/9747-33    170
  (C1) H95/4615-94     72
  (C1) H2001/2913-12   58
MD-s12                 15
MD-s15                 18
MD-s11                 14
  (C1) H96/7239-26    103
MD-s1                   4
  (C1) H2000/11001-6  175
  (C1) H2001/11562-2  176
MD-s6                   9
MD-s8                  11
MD-s4                   7
  (C1) H96/7531-16    115
MD-s3                   6
MD-s5                   8
  (C3) H99/7638-1     119
  (C3) H99/7794-3     143
  (C3) H87/86-229      40
  (C3) H87/86-236      41
  (C3) H87/86-228      39
  (C3) H93/3710-70     67
  (C3) H99/8760-77    157
MD-s10                 13
```


Section C
C A S E
0
5
10
15
20
25
(C1) H88/340-24 43
(C3) H97/7780-10 121
(C3) H98/8364-5 146
(C3) H96/7333-22 106
(C3) H97/7780-8 122
(C3) H99/8490-103 153
(C3) H2000/9445-2 166
(C3) H97/7784-31 142
(C2) H96/7414-47 112
(C2) H2000/8983-44 159
(C2) H97/7784-29 140
(C2) H98/8407-39 147
(C2) H2000/9973-13 174
(C2) H95/4613-42 71
(C2) H96/7105-8 98
(C2) H2000/2230-16 48
(C2) H2000/8992-1 160
(C2) H2000/2301-17 50
(C2) H2000/2301-17 51
(C2) H97/7784-22 134
(C2) H97/7784-28 139
(C2) H99/8492-229 154
(C2) H96/7410-1 109
(C2) H99/8956-1 158
(C2) H97/7784-18 130
(C2) H97/7784-20 132
(C2) H2000/2230-17 49
(C2) H98/8487-32 151
(C2) H2000/8997-4 161
(C2) H97/7784-17 129
(C2) H97/7784-25 137
(C2) H2000/9443-7 164
(C3) H95/5802-5 89
(C3) H95/5803-25 90
(C3) H99/7636-8 117
(C3) H99/7637-32 118
TH-s3 36
(C3) H2001/2939-25 61
TH-s1 34
(C3) H97/7784-157 125
(C3) H97/7784-158 126
MD-s13 16
(C3) H95/4919-62 77
(C3) H96/7106-27 99
(C3) H96/7118-9 100

## Section D


C A S E
0 5 10 15 20 25
(C3) H95/4723-2 73
(C3) H99/8497-3 155
MD-s9 12
MR-s10 28
MR-s12 30
MR-s1 19
MR-s2 20
MR-s6 24
MR-s7 25
MR-s4 22
MR-s5 23
MR-s3 21
MR-s8 26
(C4) H97/7784-19 131
(C4) H98/8342-3 144
(C4) H2000/9447-5 167
(C4) H97/7784-156 124
(C4) H98/8407-40 148
(C4) H98/8486-50 150
(C4) H98/8410-12 149
(C4) H2000/9442-2 162
(C4) H96/7414-46 111
(C4) H89/1121-5 45
(C4) H2000/9443-6 163
(C4) H97/7784-24 136
(C4) H97/7784-159 127
H2000/9840-8 173
H97/7784-27 138
(C4) H2000/2774-14 54
(C4) H96/7401-63 108
TH-S2 35
H96/7467-658 113
LOR-s1 2
H2000/9445-1 165
LOR-s2 3
MR-s9 27
MR-s13 31
NS-s1 33
NGW-s1 32
GD-s1 1
H98/8668-2 156
MR-s11 29

# APPENDIX 7.12

# NOTES ON EXPERIMENTAL HEATING OF BLACK STEATITE FROM MEHRGARH

In May of 2004, Dr. Jean-François Jarrige and Catherine Jarrige kindly provided me with a small set of steatite artifacts from the site of Mehrgarh for use in geologic provenience analyses and experimental heating studies. Among the set were a number of jet-black bead roughouts and fragments that, along with several hundred other such artifacts, had been recovered from an MR4 atelier dating to the early Chalcolithic Period (Mehrgarh IIB – ca. 5000 BC) (Jarrige 1981: 99). Seven of the atelier artifacts were examined using INAA (Chapter 7 – Figure 7.7 A, MR-s1 through MR-s7) and determined to likely represent steatite from a single dolomitic deposit that is, perhaps, located in central Balochistan. It had already been established in previous studies conducted by Barthélémy de Saizieu and Bouquillon (1994, 1997) that this type of steatite became white when heated. As part my effort to understand the properties that made steatite from certain sources desirable to Indus craftspeople, I decided to further document the macroscopic and mineralogical changes that "Mehrgarh Black" steatite undergoes as it is heat-treated.

A large fragment of the "Mehrgarh Black" steatite (Appendix 7.12, Figure 1 *top*) was selected for the heating experiment. Although I did not know it at the time, the fragment had a calcite phase in addition to the main talc phase (XRD was not performed until after the initial firings were complete and I had not read Vidale's 1995 article in which he also documented this secondary phase). Had I known this, I would not have used that particular fragment as I was mainly interested in documenting the decomposition of talc into enstatite and cristobolite. Barthélémy de Saizieu and Bouquillon's XRD (1994: Figure 3.4) analysis of black steatite from Mehrgarh had indicated that it was entirely talc.

The fragment I chose was cut into 16 chips (Appendix 7.12, Figure 1 *bottom*). For the first round of firings, nine chips (Set One) were heated separately in a muffle furnace at different temperatures for exactly one hour each. The numbers 4 through 12, which correspond to the temperature that each was subjected to – 400°C to 1200°C in increments of 100°C, were scratched on their surfaces. Length, width and thickness measurements were made for each chip in Set One before and after the firings (Appendix 7.12, Figure 2). This was a *static* firing in that each chip was placed into the furnace when the experimental temperature was reached and then removed immediately after the one hour. XRD was conducted on the unfired fragment and then on each fired chip (Appendix 7.12, Figure 3) to determine if and how its mineral composition had been altered by the heat to which it had been subjected. Based on the results provided by Set One, a second set (Set Two) of seven samples was static fired for three-hour periods at temperatures between 600°C and 1200°C.

## XRD OF THE UNFIRED "MEHRGARH BLACK" STEATITE SAMPLE

Both talc and calcite phases are evident in the raw sample. In their unfired state the steatite chips have a dark gray appearance with a matte textured surface.

### Observations SET ONE

***MGR 400°C @ 1 hr***

Talc and calcite phases. The intensity of the major calcite peak has dropped slightly indicating that it is




**Appendix 7.12 Figure 1** The black steatite fragment from the MR4 atelier used in this experimental study (top) and the two sets of chips cut from it before and after heating.

already beginning to decompose. The macroscopic appearance of the steatite remained unchanged.

*MGR 500ºC @ 1 hr*

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes. The talc phase remains practically unaltered. The appearance of the steatite remained unchanged.

*MGR 600ºC @ 1 hr*

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes. The talc phase is still largely unaltered.

**Appendix 7.12 Figure 2** Mehrgarh Black Steatite Heating Experiment – SET ONE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | ***Before Heat-treatment*** | | | | |
| STEATITE CHIP | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| LENGTH (mm) | 8.5 | 8.29 | 9.18 | 8.24 | 8.6 | 9.29 | 8.69 | 9.6 | 9.76 |
| WIDTH (mm) | 5.13 | 5.11 | 5.87 | 6.45 | 5.86 | 6.32 | 7 | 7.09 | 6.4 |
| THICKNESS (mm) | 1.61 | 1.92 | 1.19 | 1.67 | 2.1 | 1.89 | 1.81 | 1.49 | 1.91 |
| WEIGHT(g) | 0.1502 | 0.1998 | 0.1571 | 0.2024 | 0.2595 | 0.2712 | 0.2543 | 0.2687 | 0.2998 |
| | | | | | ***After Heat-treatment*** | | | | |
| TEMPERATURE | 400°C | 500°C | 600°C | 700°C | 800°C | 900°C | 1000°C | 1100°C | 1200°C |
| LENGTH (mm) | 8.48 | 8.26 | 9.17 | 8.15 | 8.57 | 9.35 | 8.76 | 10.01 | 10.05 |
| WIDTH (mm) | 5.1 | 5.1 | 5.87 | 6.51 | 5.87 | 6.38 | 7.15 | 7.26 | 6.74 |
| THICKNESS (mm) | 1.61 | 1.92 | 1.18 | 1.67 | 2.11 | 1.92 | 1.84 | 1.54 | 2.01 |
| WEIGHT(g) | 0.1495 | 0.1992 | 0.1563 | 0.1979 | 0.2482 | 0.2358 | 0.2071 | 0.2184 | 0.2431 |
| | | | | | ***Change*** | | | | |
| VOLUME | -0.82% | -0.56% | -0.95% | -0.17% | 0.30% | 3.21% | 4.67% | 10.35% | 14.12% |
| WEIGHT | -0.47% | -0.30% | -0.51% | -2.22% | -4.35% | -13.05% | -18.56% | -18.72% | -18.91% |

The appearance of the steatite remained unchanged.

*MGR 700°C @ 1 hr*

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes. The talc phase is largely unaltered. The appearance of the steatite remained largely unchanged although a few light gray-white patches are evident.

*MGR 800°C @ 1 hr*

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes and several of the minor calcite peaks have disappear. The talc phase is beginning to show signs that that decomposition has begun. Much of the steatite chip is now mottled with gray-white patches.

*MGR 900°C @ 1 hr*

Talc with minor calcite and enstatite phases. A single, much diminished calcite peak remains. Peaks indicating the formation of enstatite are now evident. The appearance of the steatite is now a cloudy gray-white with spots of pure white.

*MGR 1000°C @ 1 hr*

Enstatite with a minor talc phase. The calcite has entirely decomposed. Most of the steatite has converted to enstatite leaving only a few minor peaks. The appearance of the steatite is now white with spots and streaks of gray-white.

*MGR 1100°C @ 1 hr*

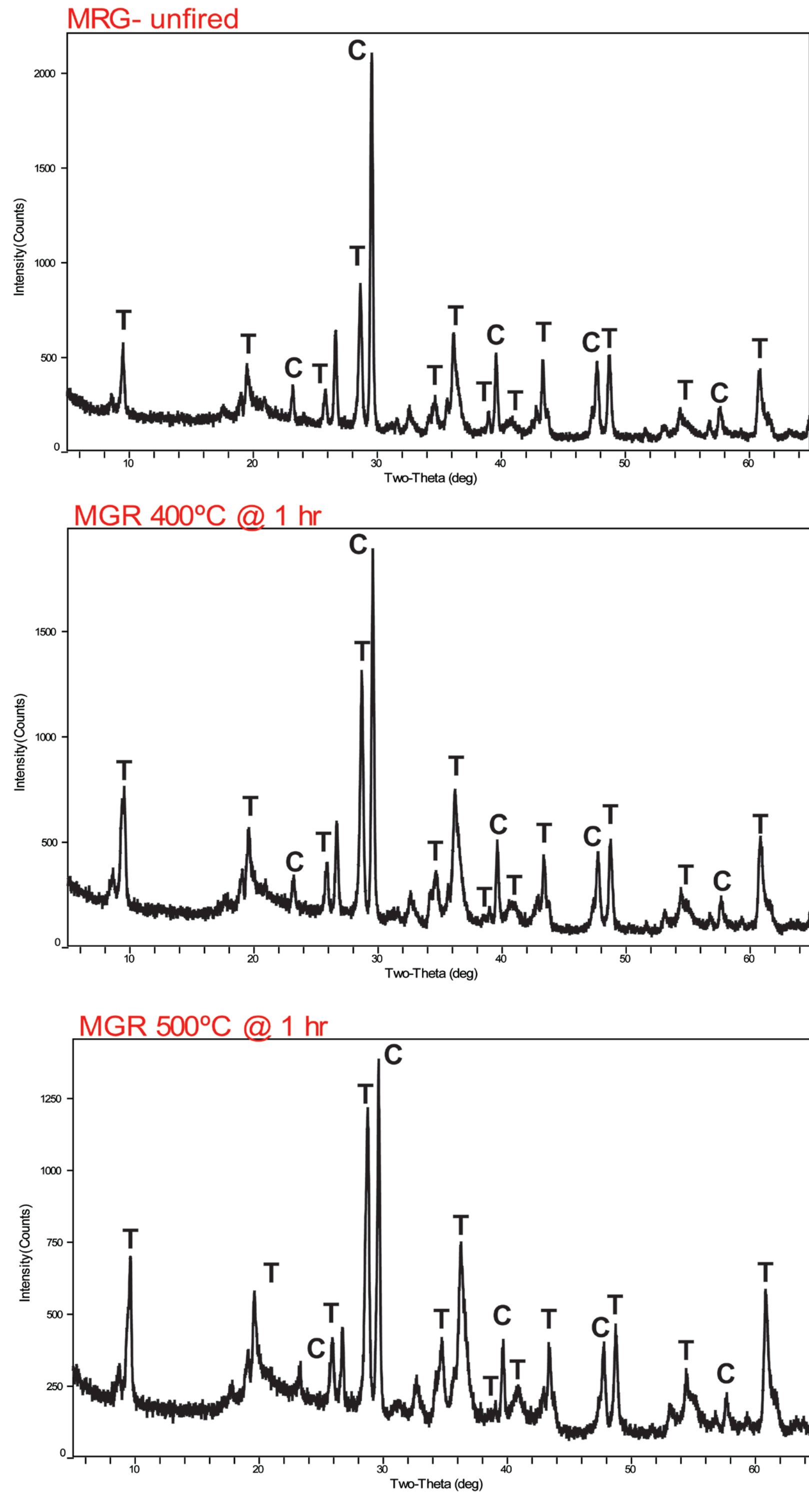
Enstatite with a minor talc phase. Enstatite is well formed while a few minor peaks for talc remain. The steatite is now almost entirely white.

*MGR 1200°C @ 1 hr*

Enstatite with cristobolite and a minor talc phase. Mostly well-formed enstatite. A few minor peaks for talc remain and strong peaks for cristobolite are now present. The steatite is entirely white.

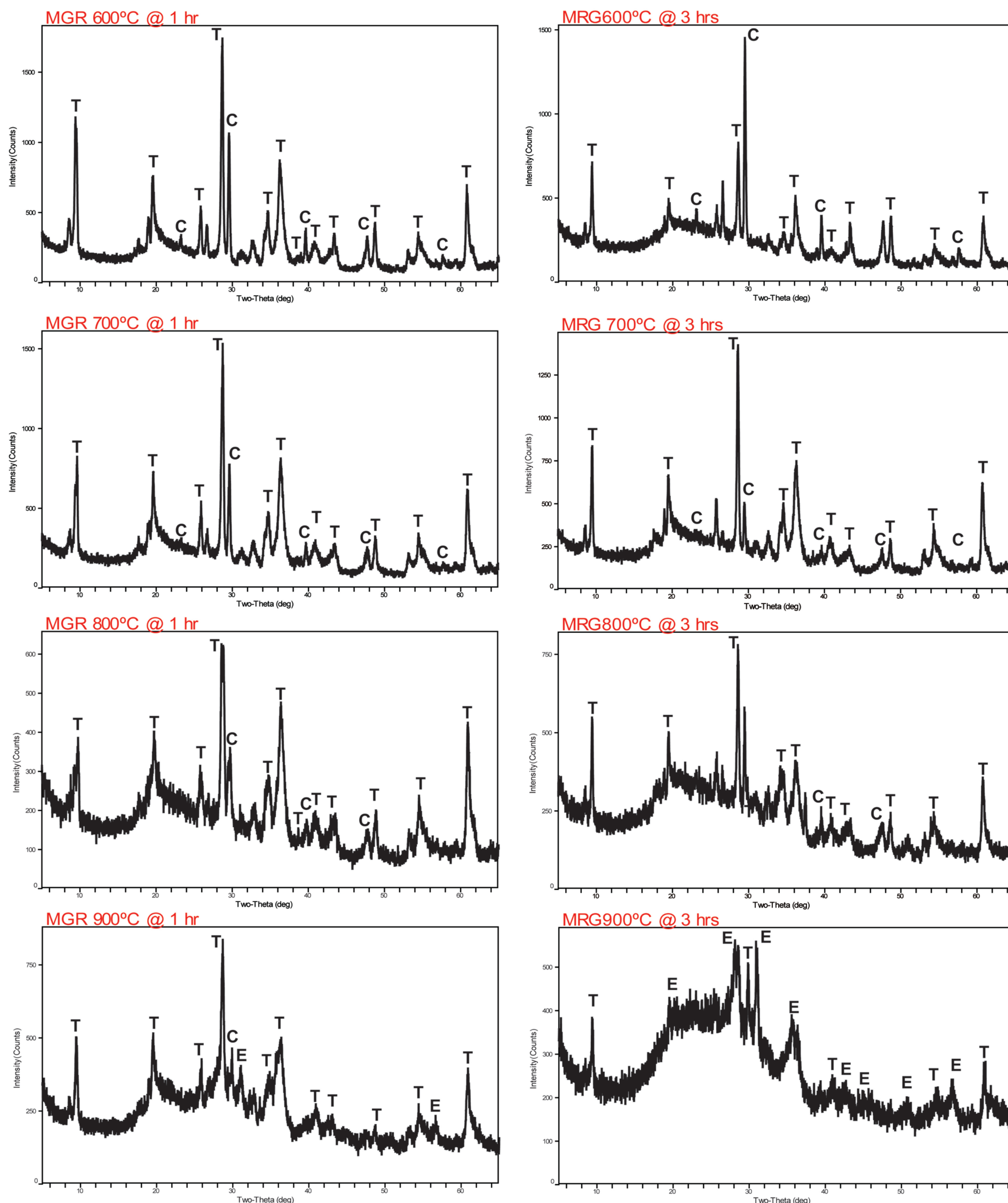
In the one hour static firings of this particular black steatite sample the conversion of talc to enstatite began somewhere between 800°C and 900°C (closer

Peak Key: **T** = talc **C** = calcite **E** = enstatite **Cr** = cristobolite




**Appendix 7.12, Figure 3** XRD scans of experimental steatite chips

to the latter judging from the peak intensities). Enstatite was fully developed by 1100°C. Cristobalite phases did not appear until temperatures approached 1200°C. A more or less fully white color was not achieved until temperatures of around 1000°C to 1100°C were reached. Although the overall drop in weight (≈ -19%) and volume (≈ -14%) was fairly significant by 1200°C, little deformation or cracking of the chips was evident.




**Appendix 7.12, Figure 3 (cont.)** XRD scans of experimental steatite chips

## Observations SET TWO

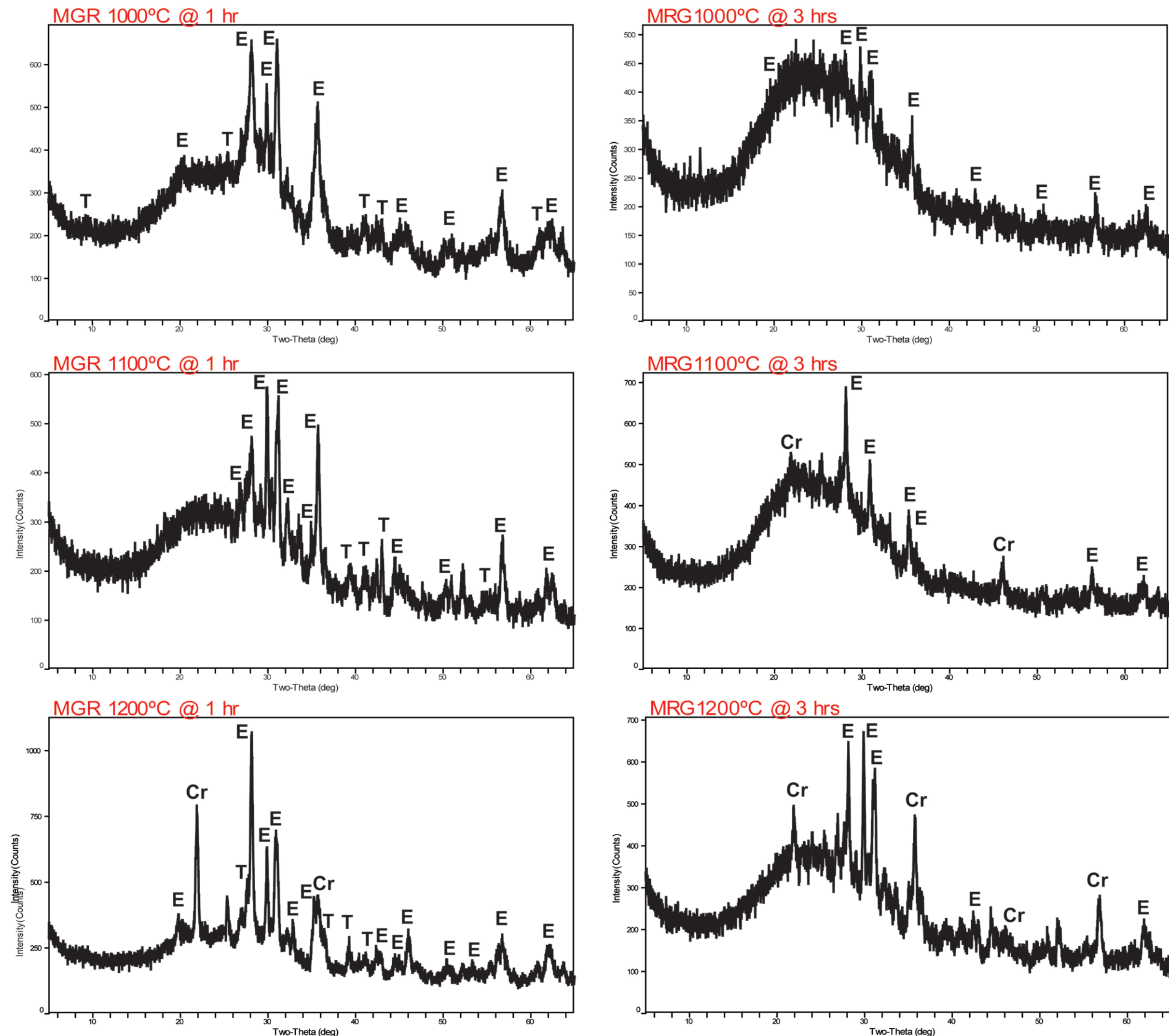
*MGR 600°C @ 3 hrs*

Talc and calcite phases. The intensity of the major calcite peak is actually much stronger here than it was in the sample that had only been heated for one hour at 600°C. A few light gray patches are evident on the chip.

*MGR 700°C @ 3 hrs*

Talc and calcite phases. The intensity of the major calcite peak has diminished significantly as that mineral decomposes. The talc phase is largely unaltered from before. A few light gray-white patches are evident on the steatite chip.

Peak Key: **T** = talc **C** = calcite **E** = enstatite **Cr** = cristobolite




**Appendix 7.12, Figure 3 (cont.)** XRD scans of experimental steatite chips

*MGR 800ºC @ 3 hrs*

Talc and calcite phases. The calcite has almost entirely decomposed. Most of the steatite chip is now mottled with gray-white patches.

*MGR 900ºC @ 3 hrs*

Enstatite with talc. The calcite is entirely gone and the talc has undergone conversion to enstatite leaving only minor peaks behind. The appearance of the steatite is now a cloudy gray-white with spots of white

*MGR 1000ºC @ 3 hrs*

Enstatite. The remaining talc has entirely decomposed. The appearance of the steatite is now white with a few gray-white spots and streaks.

*MGR 1100ºC @ 3 hrs*

Enstatite with a minor cristobolite phase. The appearance of the steatite chip is now entirely white.

*MGR 1200ºC @ 3 hrs*

Enstatite and cristobolite phases. The macroscopic appearance of the steatite chip is now entirely white.

The XRD scans of Set Two indicate that, in general, longer firing times produce more developed and, in

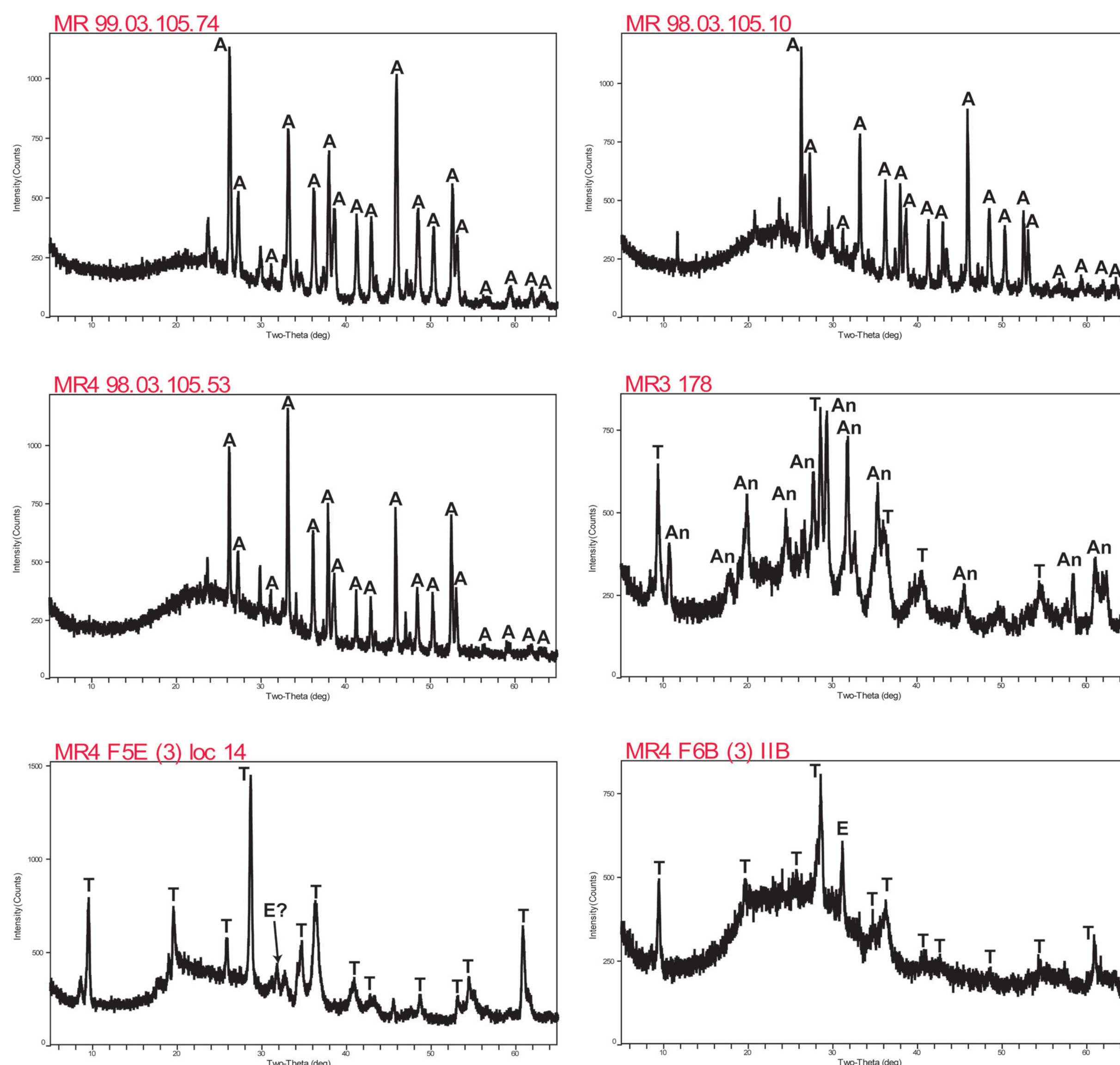
some cases, slightly earlier mineral phase changes. Enstatite still does not appear until around 900°C but it shows better peak development. Talc entirely was completely gone by 1000°C whereas it had never entirely decomposed in the 1-hour firings. Cristobolite now appears at 1100°C and is well formed by 1200°C. The appearance of the steatite still does not fully transform into a pure white color until around 1000°C to 1100°C.

# APPENDIX 7.13

## XRD CHARACTERIZATION OF SIX WHITE BEADS FROM MEHRGARH

Along with the unfired steatite artifacts discussed in the previous appendix (7.12), Dr. Jean-François Jarrige and Catherine Jarrige also provided me with six tiny white beads from Mehrgarh periods I and II levels for characterization using XRD. The scans for these beads can be found on the next page (Appendix 7.13, Figure 1) along with a peak key.

Three of the Period I beads (MR.99.03.74, MR.98.03.10 and MR.98.03.53) were determined to be composed of *aragonite* – a calcium carbonate similar to calcite. The XRD patterns of the remaining three revealed them to be made from talcose materials with characteristics consistent with those reported by Barthélémy de Saizieu and Bouquillon's in their study (1994) of Mehrgarh steatite beads from the same periods. Bead MR3 178 (from Period I) is composed




**Appendix 7.13 Figure 1** XRD scans of six white steatite beads from Mehrgarh

mainly of *anthophyllite* with secondary phases of talc. Anthophyllite is an asbestos-like mineral that, because it occurs in both ultramafic igneous and dolomitic sedimentary rocks (Deer *et al*. 1992: 235), is not particularly helpful for determining the stone's geologic provenience. The nearest reported natural occurrence is in the Sakhakot-Qila ophiolite of the Mohmand Agency, FATA (Ahmed 1987b). The mineral could, however, be related to the thermal decomposition of talc to enstatite. In experimental heating studies of talc, Greenwood reported (1963) the formation and breakdown of an intermediate stage of anthophyllite between 667° ± 8°C and 745° ± 10°C.

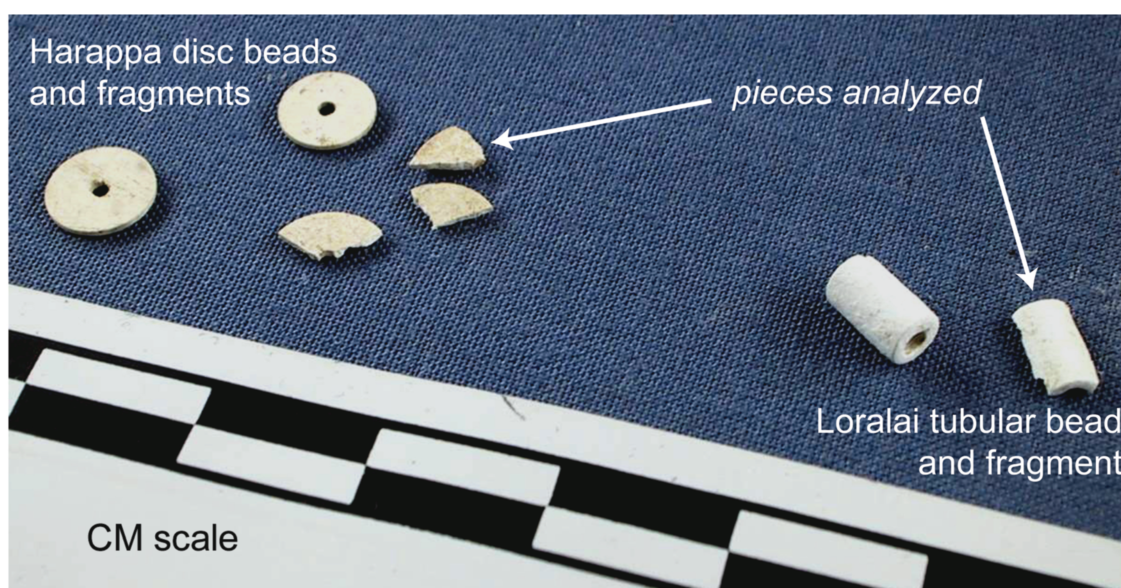
Scans of the final two white beads (MR4 F5E (3) loc 15 and MR4 F6B (3) IIB), which are both from Period IIB, revealed talc peaks and a few minor enstatite peaks. After comparing those scans to the ones produced in the experimental heating study of the Mehrgarh black steatite fragment (Appendix 7.12), I would estimate that the beads were fired at a temperature between 800 and 900°C – probably closer to 900°C given the presence but poorly developed appearance of the enstatite peaks. That temperature is consistent with Barthélémy de Saizieu and Bouquillon's previous estimate (1994: 51) for fired steatite beads of this period.

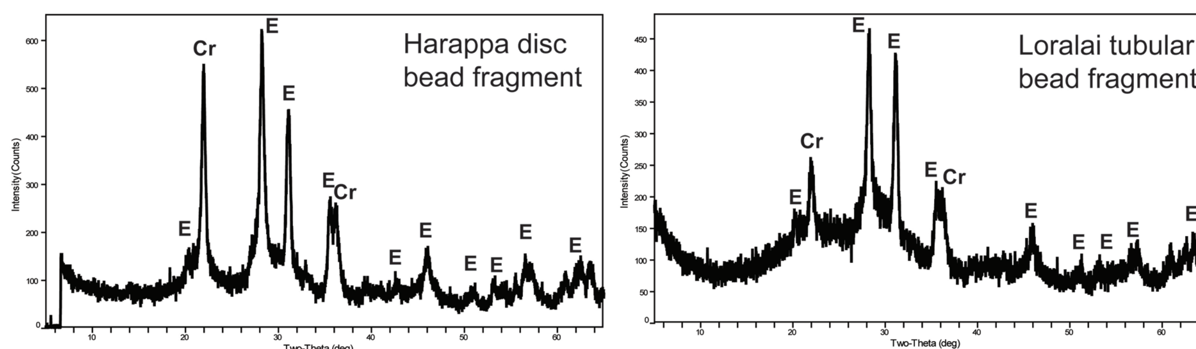
# APPENDIX 7.14

## XRD AND EMPA CHARACTERIZATION OF STEATITE BEADS FROM HARAPPA, LORALAI AND GOLA DHORO

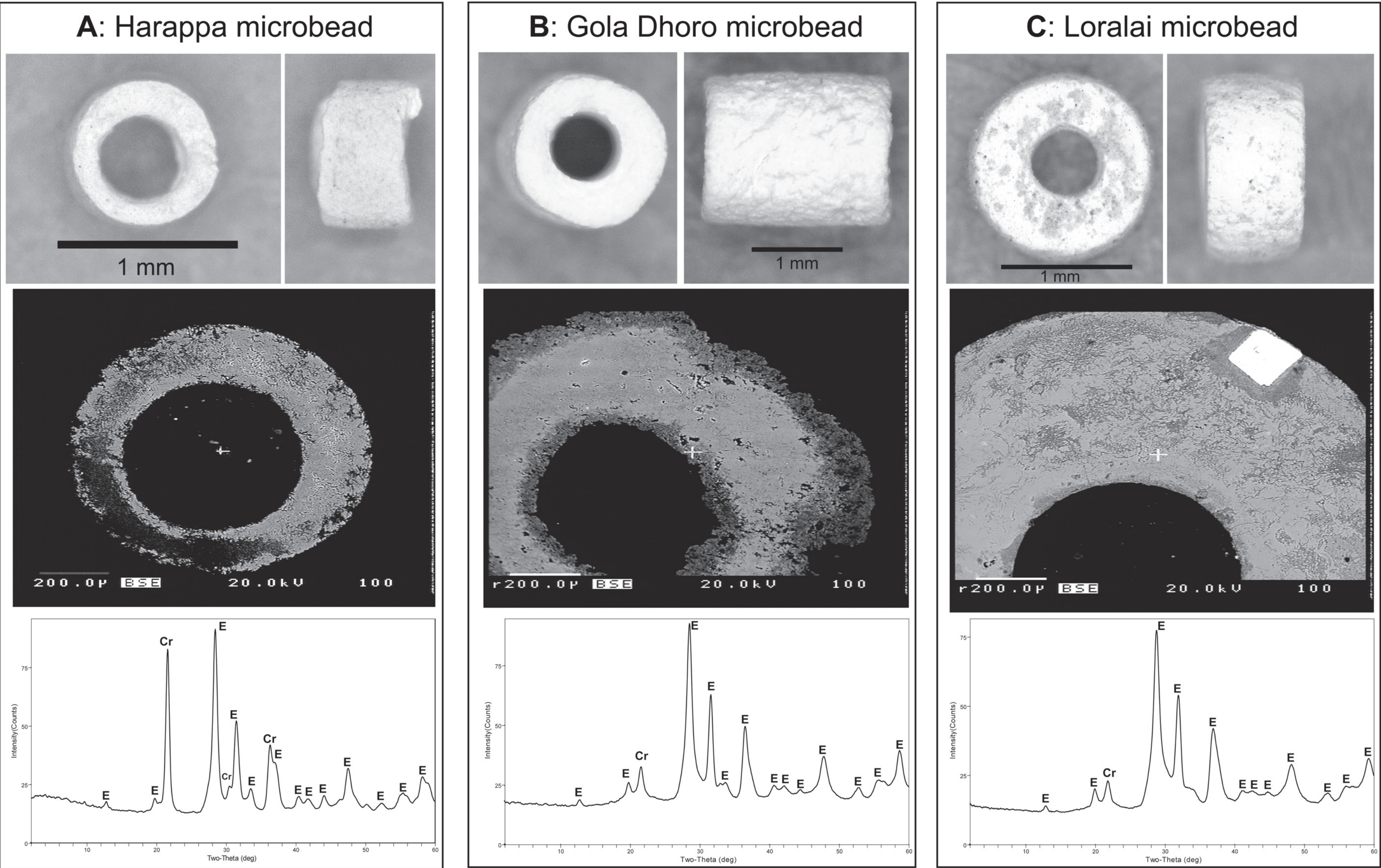
The thermal decomposition of the mineral talc into enstatite and cristobolite can provide an accurate indication of the temperatures achieved during the firing of steatite artifacts. In this appendix, steatite beads from three sites are characterized using XRD and EMPA.

For the first round of analyses, XRD was conducted on fragments of two artifacts that had clearly been fashioned from solid pieces of steatite. One was of a disc bead (Appendix 7.14, Figure 1 *top left*) from Harappa that was in a bag of miscellaneous surface finds from Mound E (H94/4999). Linear marks from the saw used to cut the solid steatite were still visible on the surfaces of the fragments. The second artifact analyzed was a broken tubular bead fragment (Appendix 7.14, Figure 1 *top right*) provided by Syed Ghani of the Geological Survey of Pakistan-Quetta. It was said to be from a mound in the Loralai District of Balochistan that is in the general vicinity of the Early Harappan site of Rana Ghundai (Ross




**Appendix 7.14 Figure 1** Steatite beads from Harappa and a prehistoric site in the Loralai District, Balochistan (top) and their respective XRD spectrums (bottom).




**Appendix 7.14 Figure 2** Steatite microbeads from Harappa **[A]**, Ghola Dhoro **[B]** and Loralai, BSE images of their sections and their Rigaku II-made XRD spectrums **[C]**.

1946). Marks from the made during the grinding of the steatite raw material prior to firing were faintly visible on the bead fragment's surface.

The XRD spectrum of the disc bead fragment from Harappa (Appendix 7.14, Figure 1 *bottom left*) indicates that it is composed of enstatite (E) and cristobolite (CR). The cristobolite is very well developed suggesting that a firing temperature of close to 1200°C was achieved (compared the scan of the disc bead to that for experimental sample from Mehrgarh [Appendix 7.12, Figure 3] that was fired for 1 hour at 1200°C). The scan of the Loralai tubular bead fragment (Appendix 7.14, Figure 1 *bottom right*) shows that it is also composed of enstatite and cristobolite. However, the cristobalite is not as well-developed as it is in the disc bead from Harappa. This probably indicates that a firing temperature of only around 1100°C was reached (compared the scan for the Loralai bead fragment to that for the Mehrgarh sample [Appendix 7.12, Figure 3] that was fired for 3 hours at 1100°C).

A second round of analyses were conducted on steatite "microbeads" from Harappa, the site of Gola Dhoro in Gujarat and the unnamed mound in Loralai (Appendix 7.14, Figure 2 A, B & C). Exactly how Indus craftspeople created extremely small ornaments such as these is poorly understood. Some researchers have speculated that they were made by carving and drilling blanks of solid steatite that were then reduced by grinding while others have argued that they were fashioned from a paste composed of talc powder and a clay mineral binding medium (see Vidale 2000: 64-66 for a more detailed review of the various theories regarding the manufacture of these objects). I tend to favor the former hypothesis based on my limited characterizations of the three microbeads using EMPA. The BSE images of the beads' sections suggest that there is solid steatite beneath their heavily weathered surfaces. The Loralai bead even has a complete calcite crystal within its matrix (recall that calcite was detected in the raw steatite sample from Mehrgarh analyzed for Appendix 7.12), which, quite obviously, had to have formed in situ. Also, EDS scans made at various points across the beads' sections detected no evidence of aluminum that would indicate they were composed of a talc mixed with a small amount of clay. These observations are cursory, however. The problem of the manufacture of Harappan microbeads remains, as Massimo Vidale has stated (2000: 66) very much "open to further archaeometric analysis and debate".

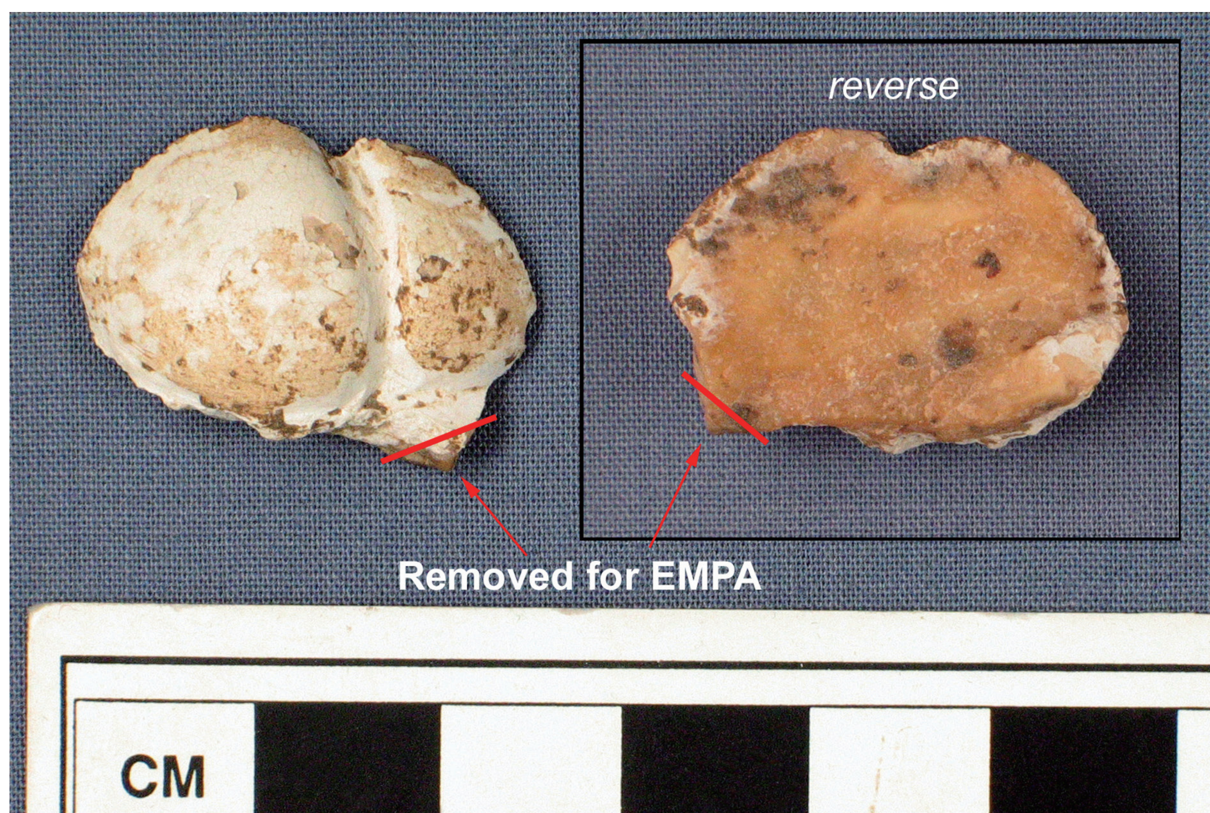
The results of the XRD analyses, on the other hand, are quite clear: the three Harappan microbeads are high-fired ornaments. Cristobalite as was detected in all of them and was especially well-developed in the example from Harappa. Hegde and others (1982) likewise detected a cristobalite phase in the microbeads they analyzed from the site of Zekhada in Gujarat. It now seems clear then that by the third millennium BC, craftspeople in many parts of the Indus realm were heating steatite to temperatures that exceeded 1100°C and, perhaps, approached 1200° C.

# APPENDIX 7.15

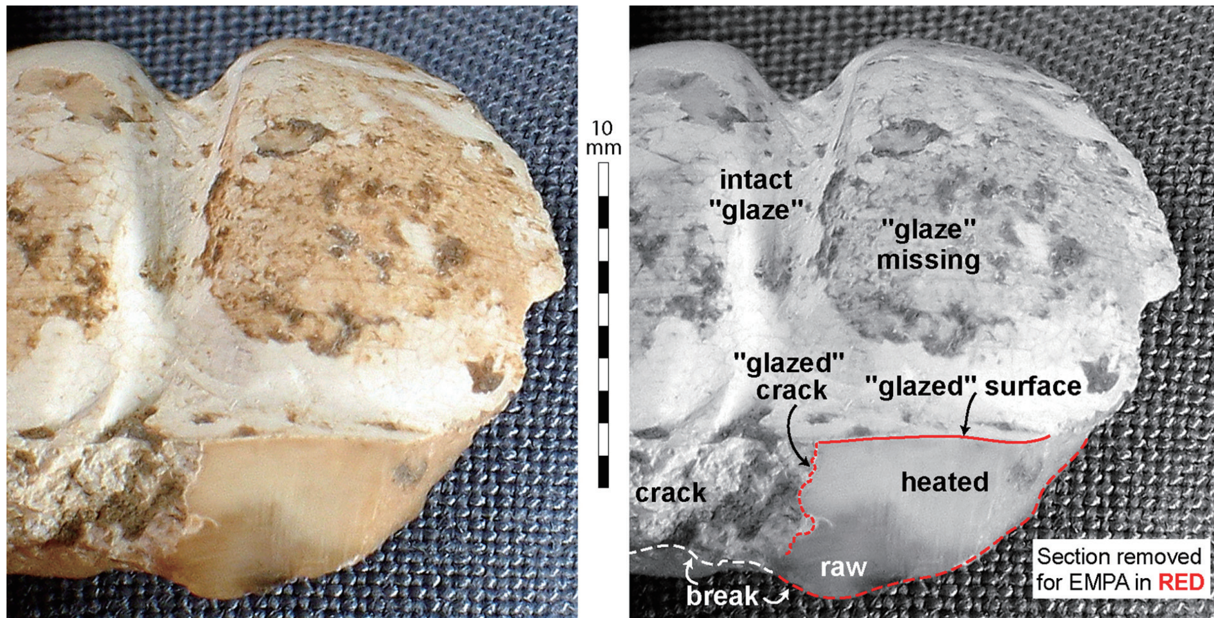
# EMPA, VP-SEM AND XRD OBSERVATIONS OF A STEATITE SEAL BOSS FROM HARAPPA

## INTRODUCTION

In Appendix 7.16, I will show that certain types of steatite become pure white when heated (fired) without having been subjected to any form of pre-treatment whatsoever. It is clear that some Harappan seals were made from this type of material as there are broken examples in which the interior is exposed to reveal that they have become white throughout. However, many other seals have thin, enamel-like white exteriors covering non-white or unfired steatite interiors. These have obviously been subjected to a surface treatment of some kind. The exact nature of that treatment is poorly understood, however (Miller 1999: 309). Some researchers have proposed that a thin glaze or slip was applied to seals (Mackay 1931d; Sana Ullah 1931) while others have argued that they were subjected to some kind of surface whitening agent, perhaps an alkaline solution (Beck 1934; Kenoyer 1998; Vidale 2000; Wheeler 1968: 101). In this appendix, I present observations made of the surface and interior of a steatite seal boss – the perforated knob that is found on the reverse sides of seals – using electron microprobe analysis (EMPA), a variable-pressure scanning electron microscope (VP-SEM) with an energy dispersive spectrometer (EDS) and X-ray diffraction (XRD) analysis. Although the results of these analyses do not definitively establish




**Appendix 7.15 Figure 1** The "glazed" exterior (left) and unfired or "raw" steatite interior (right) of the seal boss with the piece removed for EMPA noted in red.




**Appendix 7.15 Figure 2** View of the steatite seal boss and the section cut (left) and features on the boss / section labeled (right).

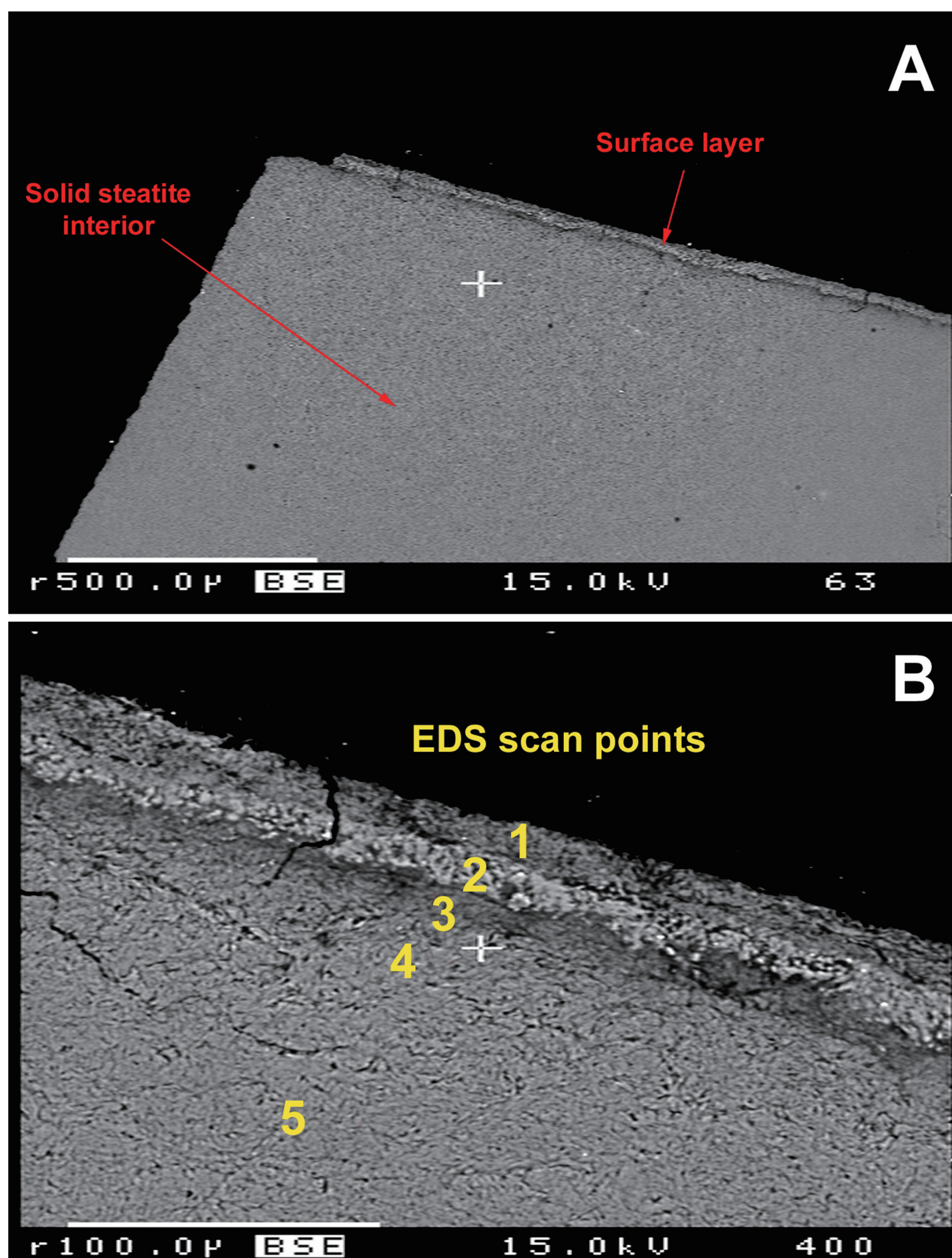
how the white surfaces of steatite seals were created, they do, in my opinion, lend strong support to the view that the objects were covered with a thin talcose slip.

## BOSS DESCRIPTION AND SUMMARY OF PAST WORK ON SEAL SURFACE TREATMENTS

Artifact H90/3208-68 (Appendix 7.15 Figure 1) is a portion of a boss that broke away, in antiquity, from a steatite seal (see Figure 7.5 F right in Chapter 7 of this book for a reconstruction what it probably looked like prior to breaking off). It was recovered in Period 3C levels in Trench 59 on the south side of Mound E at Harappa. A sample of unfired steatite was removed from the boss' underside for INAA analysis. The results (listed in Appendix 7.1) indicate that the raw material is most closely related to steatite from the Daradar (PD) deposit in the Kurram Agency, FATA.

The exterior surface of the boss is white and is rife with fine cracks that are reminiscent of a glaze that has undergone crazing. In places this "glaze" (if indeed that is what it is) has fallen away to reveal the off-white fired steatite subsurface beneath it. The khaki-colored unfired or "raw" steatite that the seal was carved from is visible on the broken reverse side of the boss. Heat-treatment (presumably) has altered the raw steatite from the surface to a depth of between one and four millimeters. This discolored (light khaki-colored zone) can be most clearly seen in the section exposed when a sliver of the seal was removed for EMPA (Appendix 7.15 Figure 2). A rough fractured area at the base of the boss is the remains of a substantial crack (labeled "crack" on Appendix 7.15 Figure 2 right) in the body of the seal. It clearly existed during the manufacture of this object as it exhibits the same "glaze" and/or treatment as the surface of the seal. This crack is probably is the reason (or part of the reason) why the boss broke from the seal body. That could have happened during manufacture or the crack may have weakened the boss causing it to snap off later.

In his study of seals from Mohenjo-daro, the Archaeological Survey of India's chemist K.B.M. Sana Ullah concluded (1931: 688) that the exterior of those artifacts was coated with a talcose slip. An analysis of the surface layer of one (ibid.: 689, Table 1 #8) indicated that it was primarily composed of




**Appendix 7.15 Figure 3** EMPA of the seal boss. **[A]** BSE image of boss section. **[B]** BSE detail of the surface layer and the EDS scan locations.

magnesium silicate with only a trace amount (1.8%) of water. This layer is almost certainly talc that has thermally decomposed to enstatite. Sana Ullah proposed that the slip was made from powdered steatite that has been previously fired (this was already enstatite). A trace amount alumina and ferric oxide (2.4% total) was also detected in the surface layer. This may indicate that a minute quantity of iron-rich

clay was added to the talcose slip, perhaps as a binder. However, in his experimental attempts to replicate the white surface, Sana Ullah instead added "silicate of soda" (sodium silicate – $Na_2SiO_3$) to powdered fired steatite. He found that this method produced "durable coatings, similar to the ones on the seals" (ibid.: 688).

Based on thin-section studies of Harappan seals, Horace Beck concluded (1934: 80-81) that "the surface had not been added as a paste, but that the seals had been carved completely from a block of steatite, and then treated with an alkali and heated." Both Kenoyer (1998: 73) and Vidale (2000: 62) concur that, rather than being covered by an applied slip/glaze, the seals were subjected to some type of alkaline mixture – perhaps calcium carbonate ($CaCO_3$ or "free lime") and potassium hydroxide, (KOH or "potash"), prior to firing. A slip, it is argued (Mark Kenoyer personal communication 2004), would obscure the finely carved details and minute manufacturing marks that are plainly visible on surfaces of seals. Soaking them in an alkaline solution and then applying heat would essentially "bleach" the surface leaving any details/marks intact.

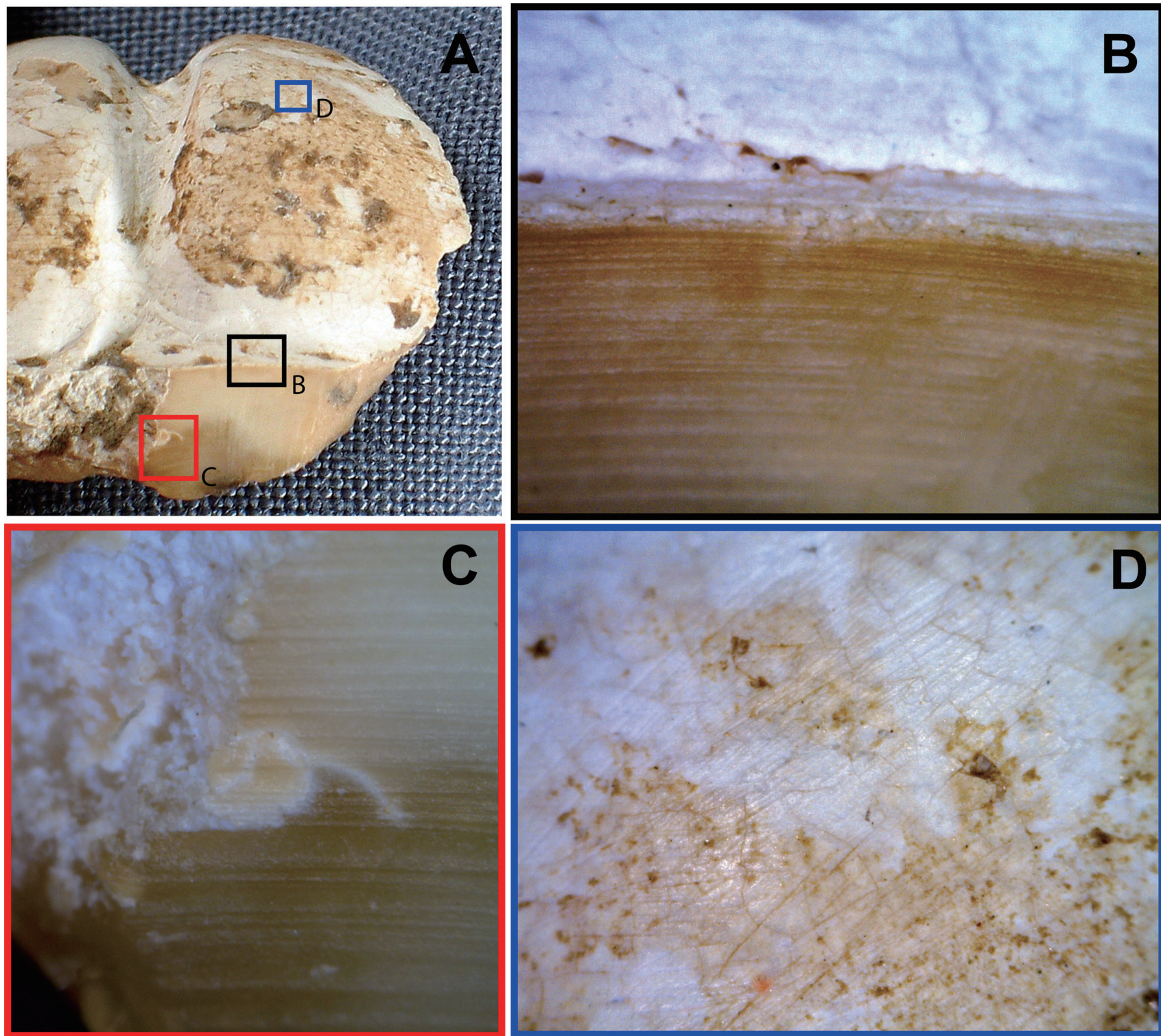
In order to evaluate the two different explanations for the white exterior of Harappan seals – i.e, glaze vs. surface treatment, observations of the seal boss were made using EMPA, VP-SEM and XRD.

## EMPA

EMPA of the seal boss described above was conducted in January 2005. A small piece that is actually a remnant of the flat reverse side of seal rather than of the boss itself was sawn from the artifact (red lines and arrows on Appendix 7.15 Figure 1 indicate the portion that was removed). This piece (≈ 7 mm in width) was prepared according to the methods outlined in the EMPA section of Chapter 3. The section left by its removal is displayed and labeled in Appendix 7.15 Figure 2. A thin white layer is plainly visible on the seal surface portion of the section as well as along the contours of the crack on its left hand side. The contrast between the heated portion of the seal body and its unaltered steatite interior is likewise evident in the section.

Appendix 7.15 Figures 3 shows two back scattered electron (BSE) images of the prepared seal sample. In image A, a surface layer approximately 35 microns (0.035 millimeter) thick stands in contrast to the homogenous steatite of the seal's immediate subsurface interior. Image B is a detail of that layer. Three sub-layers are visible (labeled on the figure as 1, 2 and 3) each of which is approximately ten microns or so in width. The seal body immediately beneath the surface layers is labeled "4" and a point around 100 microns in depth is labeled "5" on the figure. At each of the five points a scan was performed using the probe's EDS, which provided fast, qualitative chemical characterizations. The composition of the material at each point was exclusively magnesium silicate. There were no peaks observable peaks in the EDS spectrum that would indicate the presence of potassium, calcium, sodium, aluminum (indicative of clay minerals), lead or any other substance that might conceivably have been added or applied as a binder, flux or colorant. Based on this, it was decided on not to calibrate the probe with mineral standards (a time consuming process) and conduct quantitative assays using its wavelength dispersive spectrometer (WDS).

Compositionally, the seal's surface layer appears identical to its interior. This could then be seen as support for Mackay's assertion (1931d: 379) "that the coating upon these seals is made of the same material as the seals themselves," that is, talc/enstatite. On the other hand, if the seal's original carved steatite surface was bleached using an alkali treatment and then heated, its basic mineralogical composition (magnesium silicate) might not have been altered very much or even at all. These initial EDS assessments, therefore, could not really provide an answer to the

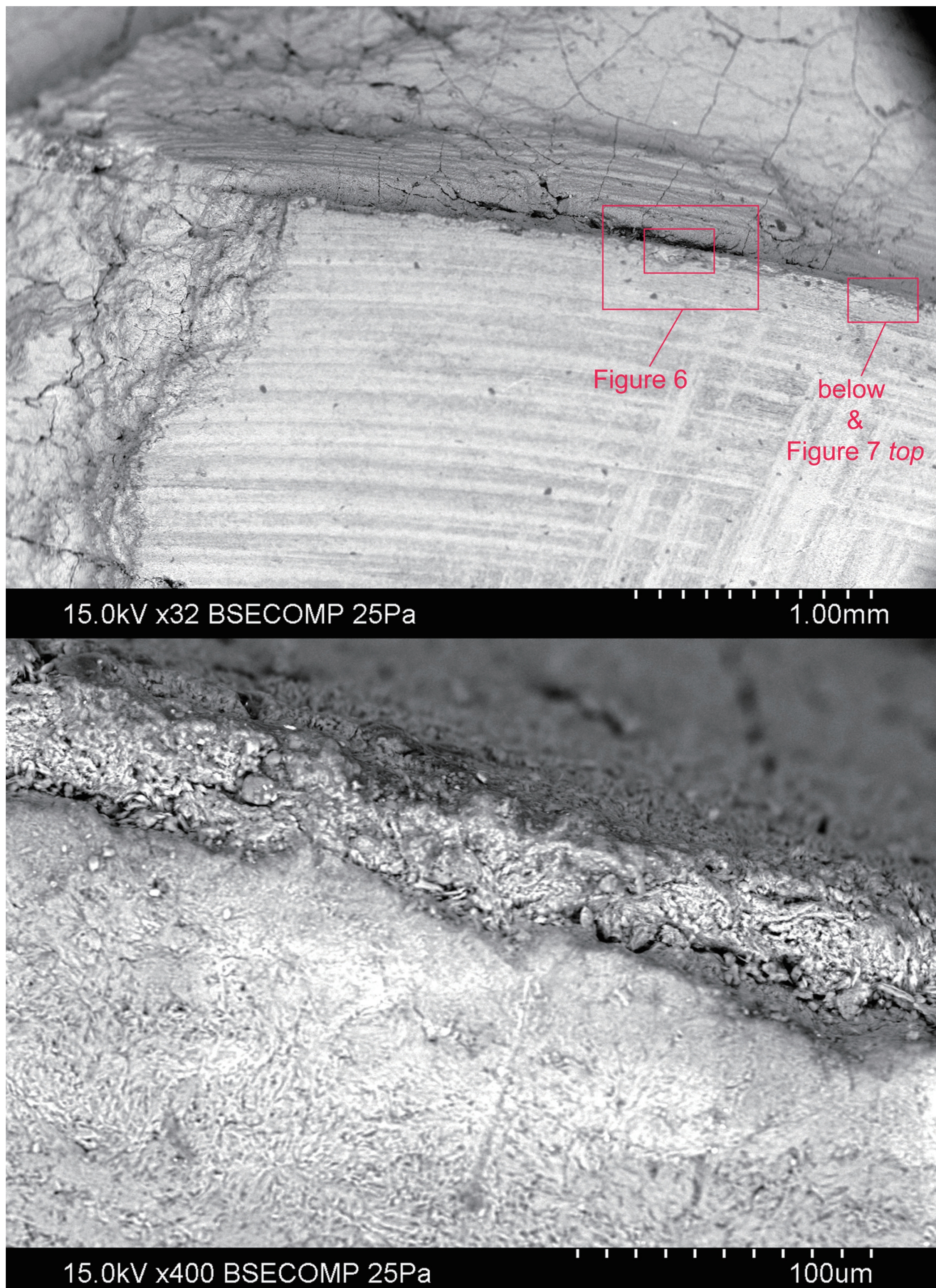



**Appendix 7.15 Figure 4** **[A]** Three areas on the seal boss chosen for BSE imaging and qualitative compositional analysis using the VP-SEM/EDS. **[B]** Visible light detail of the surface layer in section. **[C]** Visible light detail of the micro-crack in the seal body. **[D]** Visible light detail of a patchy area on the seal boss' surface.

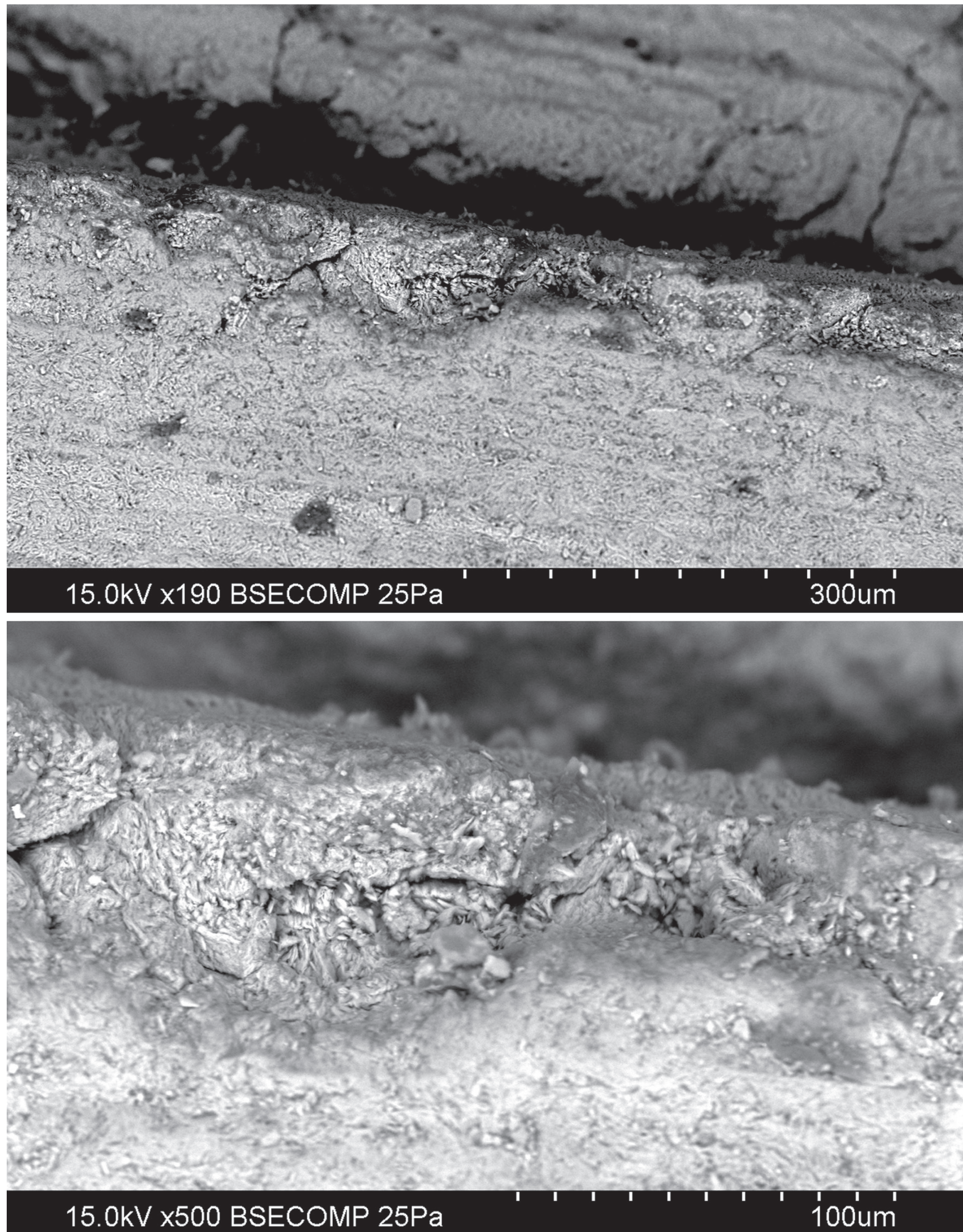
glaze vs. treatment question.

The BSE images were more revealing. Looking at Appendix 7.15 Figure 3 B, it is evident that although the platy interlocking grains of the seal's interior lighten (darken on the BSE image) as layer 3 begins, the texture remains homogenous through layer 3 up to layer 2. After that point the texture suddenly becomes much coarser. It seems to me that if there is an applied surface it probably begins at this sharp layer 2 to 3 boundary. Layer 3 may then be the original carved surface of the seal that has undergone some form of alteration due to its fusion the Layer 2. Note that the indicated micro-crack runs from the surface through layer 3. This probably explains why as the "glaze" scales off it often takes some of the original carved surface with it.

What of that original carved surface of the seal? Would not a slip obscure details and manufacturing marks? It would if a "wet glaze" (Miller 1999: 308) that was too thick and viscous was applied to a seal. However, it is possible to produce extremely fine and fluid steatite slips (Grosjean 1999). If layer marked "3" is assumed to be the original seal surface then the remaining "glaze" is only around 20 microns (0.02 millimeter) in thickness. A slip that thin could have adhered to the contours of carved details and




**Appendix 7.15 Figure 5** Top - Two areas in which detailed BSE imaging and/or EDS of the seal boss' surface layer in section was conducted. Bottom - BSE image detail of the first area examined.




**Appendix 7.15 Figure 6** Full view and detail of the second area examined on the seal boss' surface layer in section.

manufacturing marks and still left them visible. It also probably could have worked its way into and coated the crack that is evident in the seal body (labeled on Appendix 7.15 Figure 1 C), something that Beck argued (1934: 81) an applied paste would not have done.

## VP-SEM / EDS

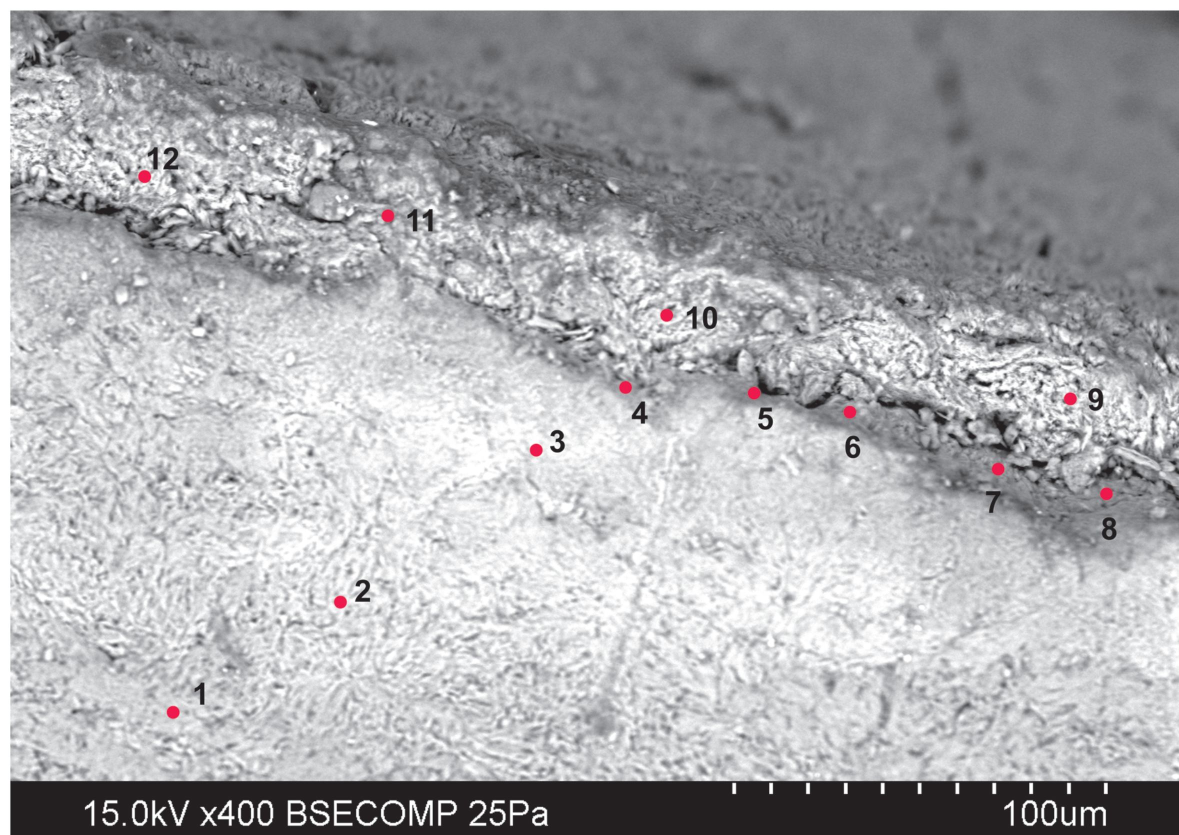
The cursory EMPA of the seal boss provided somewhat equivocal results and so follow-up studies were conducted on the VP-SEM in December 2009. There were several advantages to using this technique. The entire artifact could be placed into the instrument's vacuum chamber; it did not need to be coated with a conducting layer; and it was possible to easily and quickly move the different areas on the object to make observations. Three areas (Appendix 7.15 Figure 4 A) were chosen for BSE imaging and qualitative compositional analysis using the instrument's EDS. The first (Appendix 7.15 Figure 4 B) was along the same thin surface layer that was exposed in section when a small piece of the boss was cut for EMPA. The second (Appendix 7.15 Figure 4 C) was around a micro-crack coming off the large "glazed" break-crack that, in visible light images, appeared to filled with a white substance similar to that covering the seal's surface. It was hoped that if the seal had been placed into a liquid medium (a bleach, slip, or glaze) during its manufacture then some of that material might be preserved in a fissure in the solid steatite such as this. The third area examined (Appendix 7.15 Figure 4 D) was the surface of the boss itself in a patchy place where the white exterior was both intact and had fallen away.

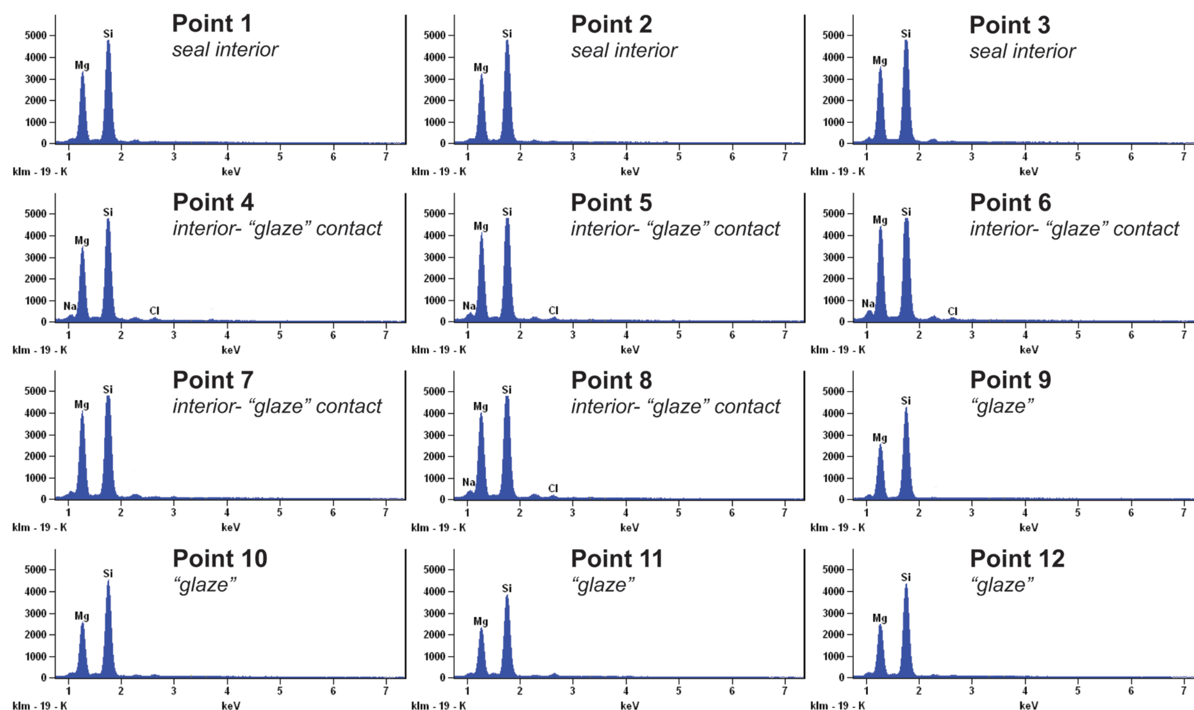
### Surface layer in section

Detailed BSE imaging of the seal boss' surface layer in section was conducted in two areas (identified on Appendix 7.15 Figure 5 top). Unlike boss piece examined using EMPA, which was finely polished prior to analysis, the section imaged on the VP-SEM was rough and the concentric marks from the circular saw used to removed the piece were visible. Nevertheless, a distinct boundary between the solid, compact steatite of the seal body and the looser material of the surface layer is evident in the first area observed (Appendix 7.15 Figure 5 bottom). The solid steatite directly below and following the contours of that boundary appears in the BSE image as a thin (5 to 10 microns), slightly gray phase. This corresponds to the Layer 3 in the earlier EMPA and would seem to be the original surface of the seal prior to the application of the final surface layer. The discoloration is probably a reaction zone created when the applied material fused or bonded with the solid steatite. In some places along the boundary there are gaps (dark areas in the BSE image) where the applied layer either did not fully adhere to the carved surface or has begun to break away.

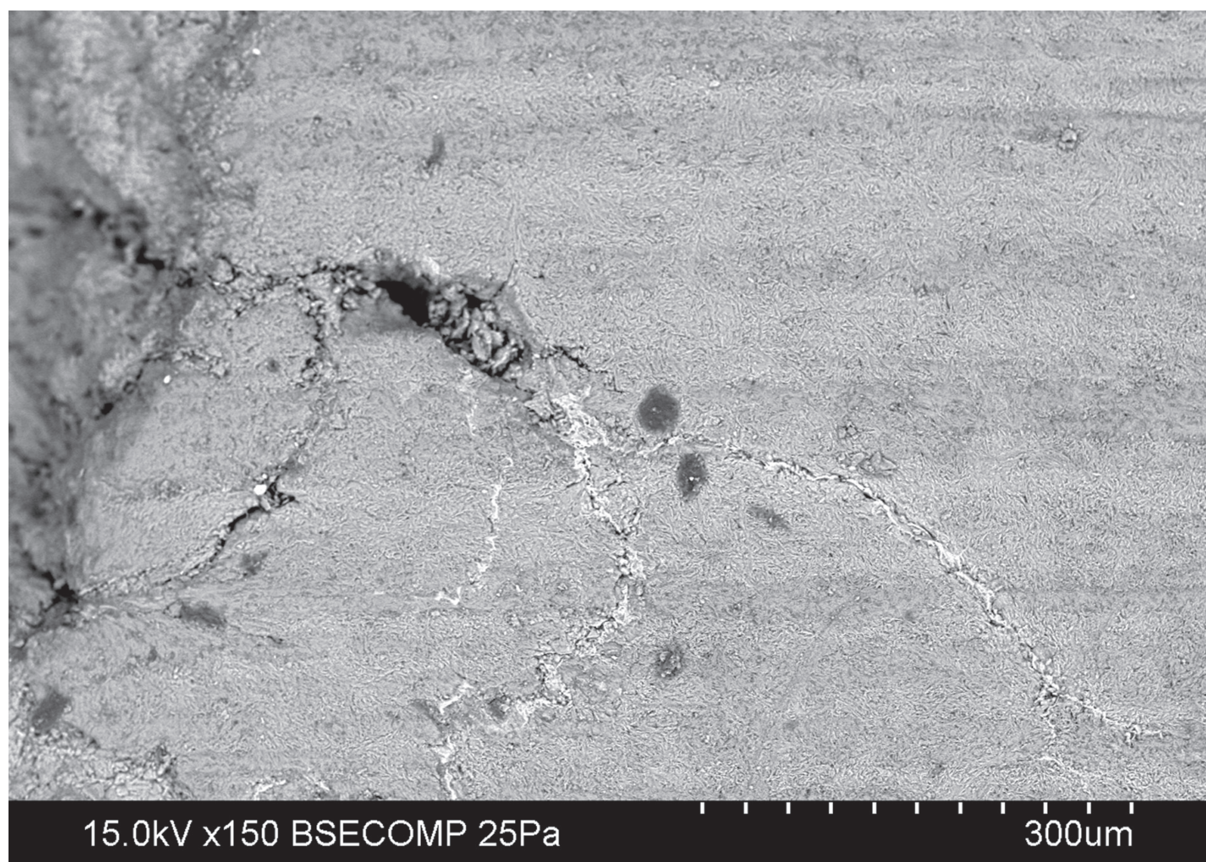
Appendix 7.15 Figure 6 shows two views (a full view - top, and a detail - bottom) of the second area imaged. This area was chosen because of a deep undulation, which could be a carving groove, in the solid steatite along the boundary where it meets the surface layer. The thin gray reaction zone observed in there first area is present again here and closely follows the contour of the undulation/groove. The difference between the solid steatite of the seal interior and the surface layer is also again striking. Although both are composed of platy crystals, those in the seal body are very tightly packed while those making up the surface layer are loose and randomly oriented. The latter almost seem to have flowed viscously into the deep groove. It is difficult to imagine what this layer could be other than applied material.

A series of 12 EDS (Appendix 7.15 Figure 7 top) scans were made along the first section of the surface layer that was imaged. Scans 1 to 3 were centered on points within the solid steatite of the seal body; scans 4 to 8 were made in the thin gray phase that at the




**Appendix 7.15 Figure 7** Top - The 12 points where EDS scans were made in the first area examined on the seal boss' surface layer in section. Bottom - The spectra for the 12 EDS scans.



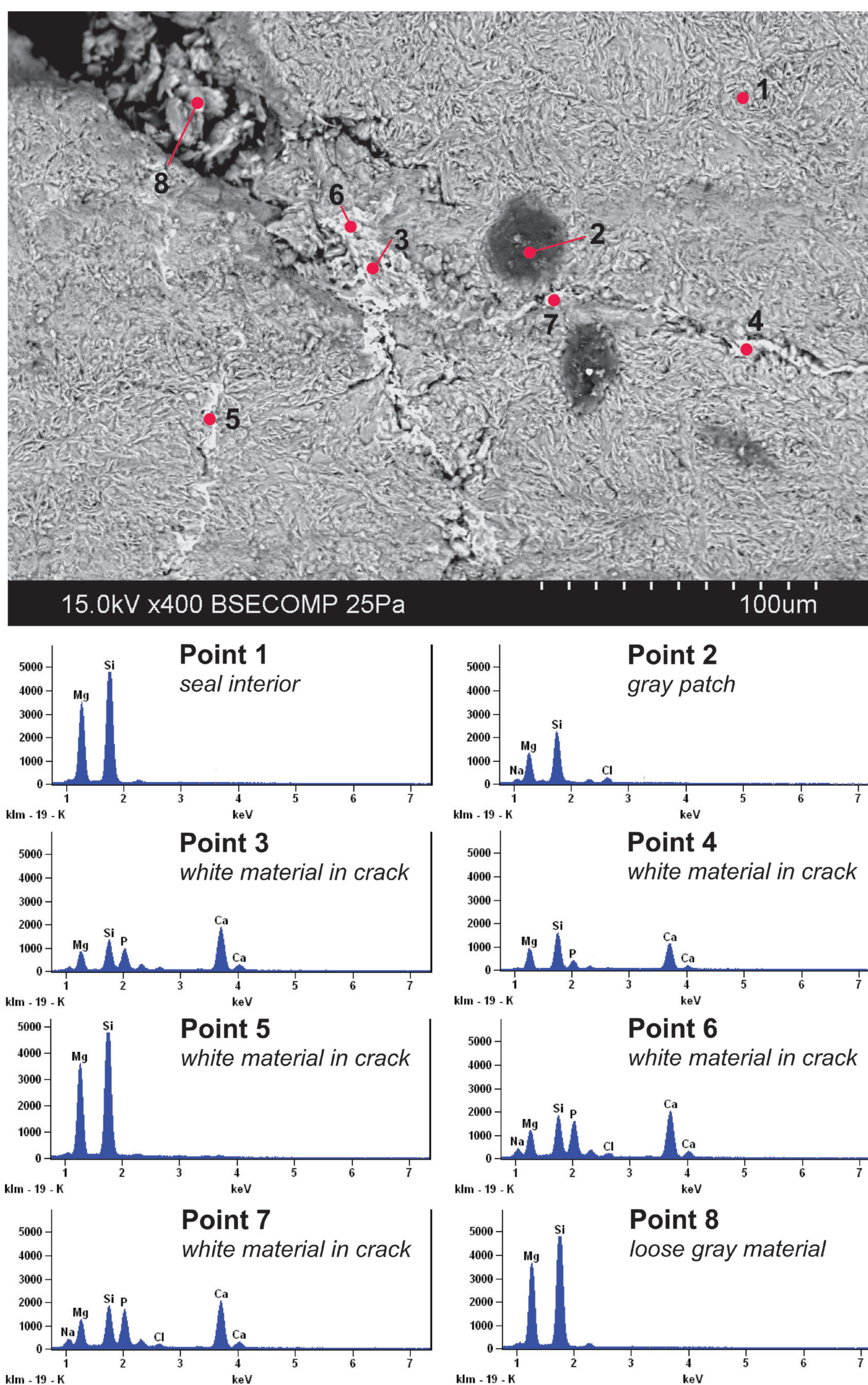

**Appendix 7.15 Figure 8** BSE image of the micro-crack in the seal boss' interior.

edge of the original seal surface that appears to be a reaction zone; and scans 9 to 12 were made at points along and within the loose material of the surface layer. The spectra for all 12 (Appendix 7.15 Figure 7 bottom) are practically identical. Like the initial EDS scans made during the earlier EMPA, those made on the VP-SEM indicated that all phases were composed solely of magnesium silicate. This was not unexpected for the scans centered on solid steatite but it was somewhat surprising with regard to the surface layer. The layer was clearly composed of talcose material but there was, again like in the EMPA, no suggestion of chemical phases that could have been remnants of fluxes, binders, or bleaches.

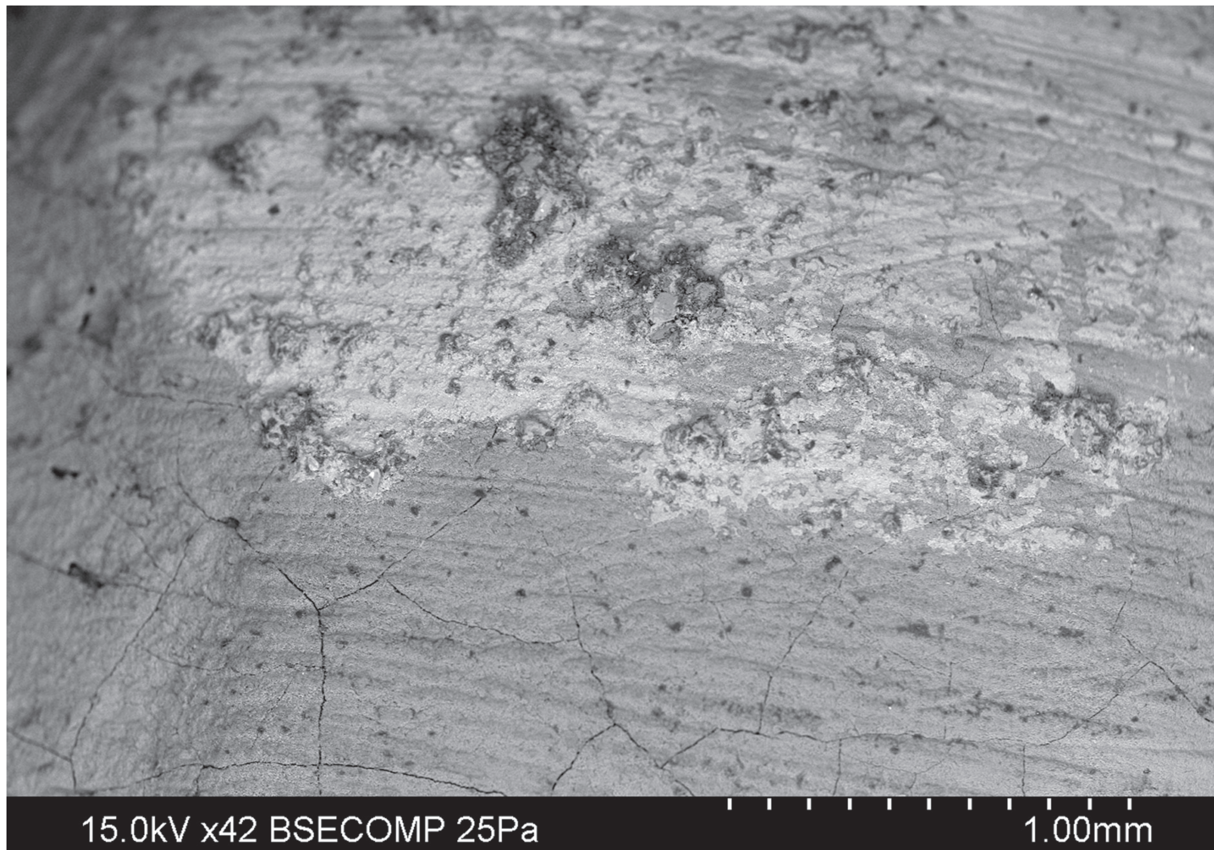
### Micro-crack

The next area examined was the micro-crack in the seal body. Appendix 7.15 Figure 8 is a BSE image of that area. The micro-crack extends from the exterior surface (which is actually a larger white-coated crack) on the upper left of the BSE image roughly 800 microns (0.8 mm) into the solid steatite matrix of the seal (the muted horizontal striping are marks across the matrix are from the saw used to cut the section). There is some loose talc-like platy material in the wide portion of the micro-crack near the surface. Deeper in the interior there a white material filling the voids created by the fissure. There are also several dark gray patches within the solid steatite matrix near the micro-crack. EDS scans were made at eight points in this area (Appendix 7.15 Figure 9 top). One was of the solid steatite of the seal interior (Point 1), another was of one of the dark gray patches near the crack (Point 2), six were of the white substance within the crack (points 3 through 7) and one final scan was made of the loose material toward the exterior surface. The spectra for those scans are displayed in the lower portion of Appendix 7.15 Figure 9.

The EDS spectrum of the solid steatite interior showed peaks for Mg and Si (MgSi - magnesium




**Appendix 7.15 Figure 9** Top - The eight points where EDS scans were made in and around the micro-crack. Bottom - The spectra for the eight EDS scans.

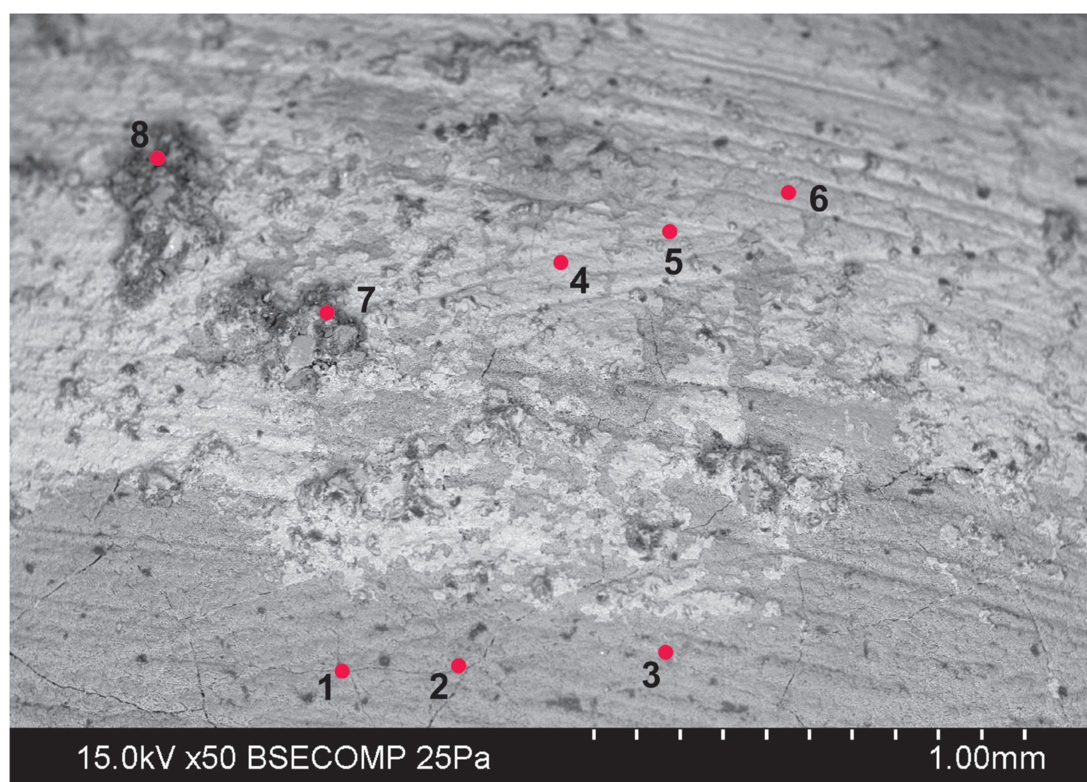


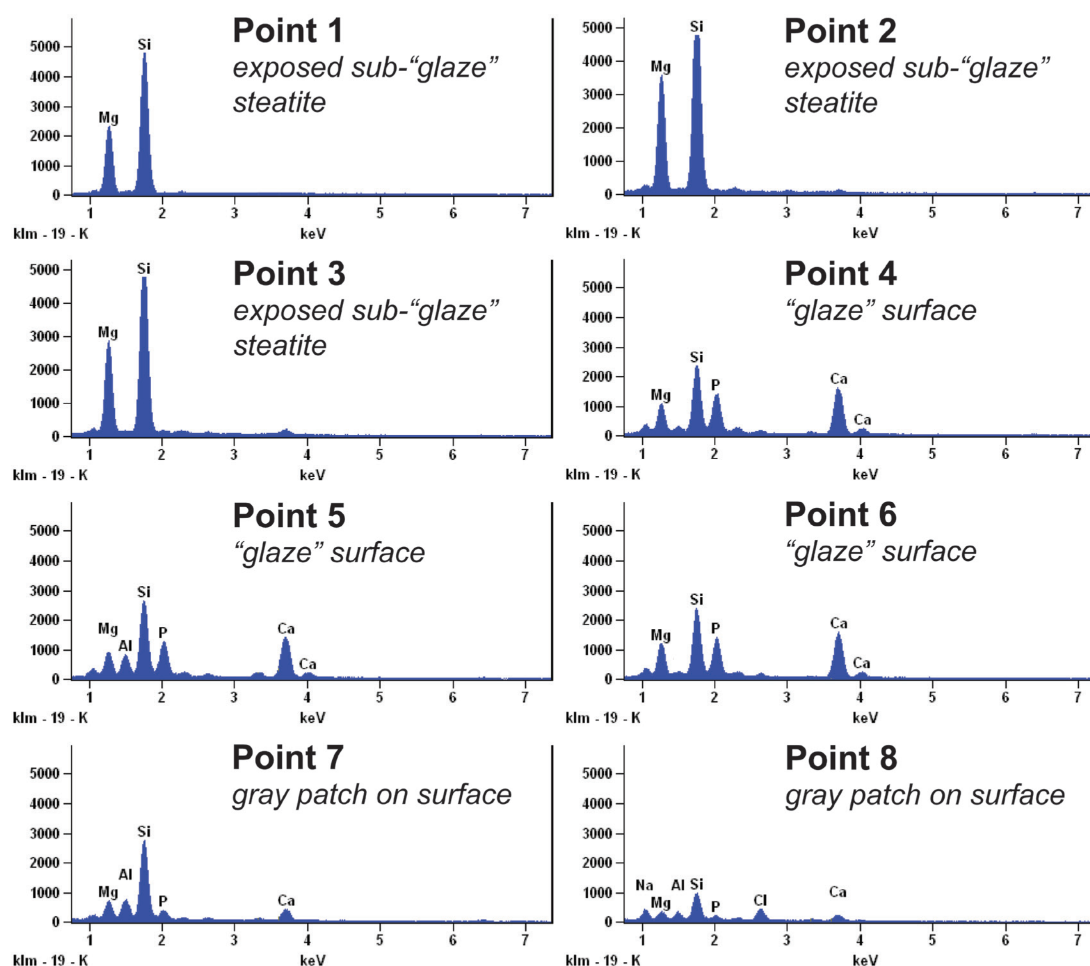

**Appendix 7.15 Figure 10** BSE image of the patchy area on the boss' surface examined using VP-SEM/EDS.

silicate) as expected. Along with MgSi, minor peaks for Na & Cl (sodium chloride) were detected in the gray patch, which indicates the presence of salt. This salty phase may have naturally occurred in the steatite body or it could have formed following the artifact's deposition in the saline soil of Harappa. Along with MgSi, peaks of Ca and P (calcium phosphate) was detected in all of the EDS scans of the white material filling the deeper potion of the crack, save for Point 5. The calcium phosphate detected could be powdered bone or bone ash. Only MgSi was detected in the spectra for Point 5. Unlike the other scans made on the white substance, the white phase here was in a crack-like area that, at least in this section, does not appear to have reached the surface of the seal. It is, therefore, probably not a crack fill with a white substance but rather a lighter phase of steatite. The loose material toward the exterior surface was also only MgSi or just talcose material.

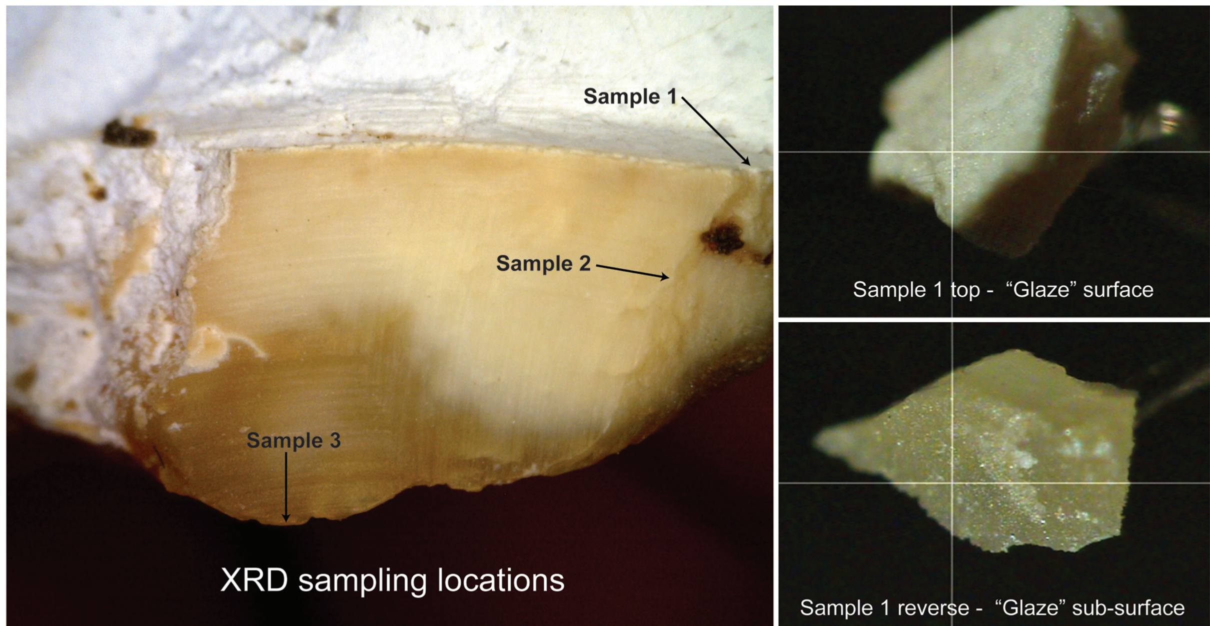
**Patchy exterior surface**

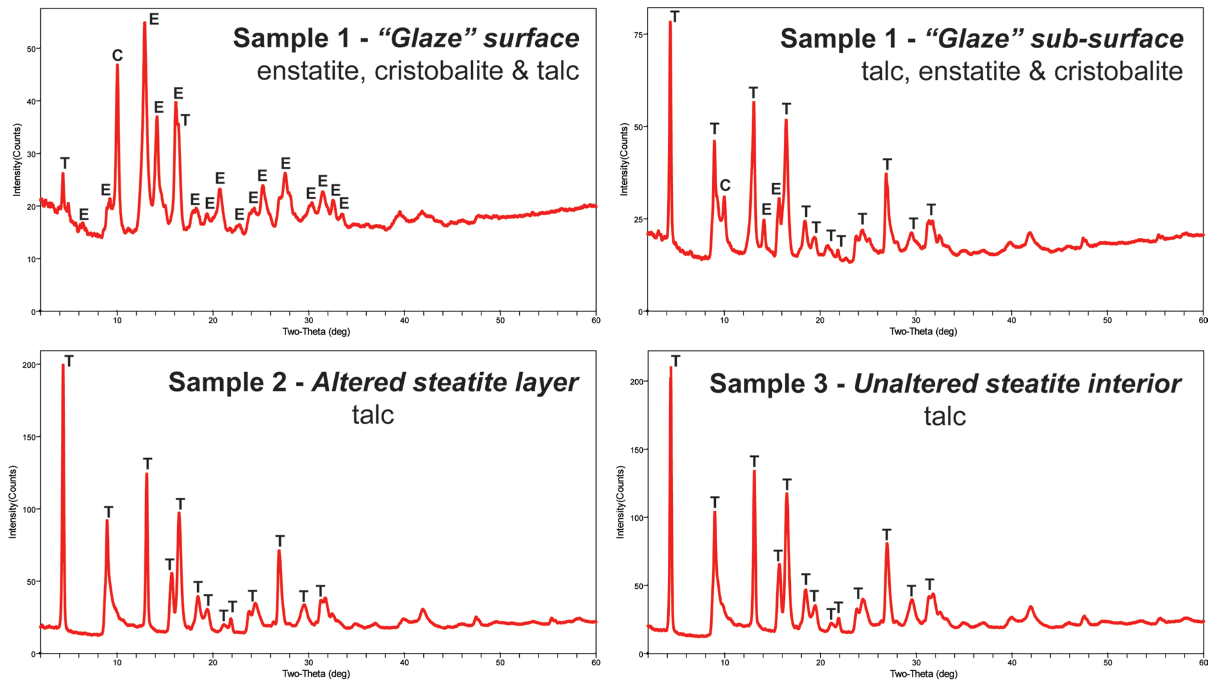
The final area examined with the VP-SEM/EDS was a place on the seal boss' exterior where there are intact patches of the treated surface as well as patches where it was missing. These are clearly visible in the BSE image of the area (Appendix 7.15 Figure 10) as bright white phases (the applied material) and gray phases (the areas where it is missing). There are also numerous large and small dark gray crusty dark patches of sediment that remained on the surface despite repeated sonic baths. An important feature to notice in the BSE image is the way in which the manufacturing striations on seal's surface continue unobscured as they pass from the applied surface areas to the places where the applied material is missing and vice versa. The fact that such marks were visible on the surface of seals has been argued to indicate that a bleach rather than a slip or glaze was responsible for the white exteriors of these objects. As we have seen,




**Appendix 7.15 Figure 11** Top - The eight points where EDS scans were made in the patchy area. Bottom - The spectra for the eight EDS scans.




**Appendix 7.15 Figure 12** Top left - Three areas on the seal boss' section where small sample of material were removed for XRD analysis. Top right two images - The surface layer sample exterior and interior side. Bottom - The XRD spectra for the three samples.

however, a distinct layer of talcose material covers the surface. That layer was obviously thin enough to adhere to the contours of the manufacturing marks without obscuring them.

EDS scans were made at eight points in this area (Appendix 7.15 Figure 11 top). Three were made where the applied surface was missing (points 1 to 3), another three were made on the applied surface itself (points 4 to 6) and two were on the dark gray crusty patches thought to be adhered sediment (points 7



**Appendix 7.15 Figure 13** Left - Carver at the shrine of Shah Noorani producing talc powder as he saws a block of steatite. Right - Bags of talc powder for sale at Shah Noorani.

and 8). The spectra for those scans are displayed in the lower portion of Appendix 7.15 Figure 10. They reveal that, as expected, the bare areas where the original, pre-application surface is exposed are wholly magnesium silicate (talcose) material. The spectra for three scans made on the applied surface, however, exhibit peaks for calcium phosphate in addition to magnesium silicate, just like the white material found deep in micro-crack. It is significant that calcium phosphate was not detected in the spectra of scans made of the applied surface in section. Those scans ran down the center of that 20 to 30 micro thick surface layer rather than along the exterior edge. This suggests that the calcium phosphate is found only on the immediate surface and was applied subsequent to the talcose layer. It almost certainly was applied as a liquid slip, which would account for the presence of the calcium phosphate within the micro-crack. Lastly, although their rough surfaces resulted in poor EDS spectra for the dark gray crusty patches, peaks of Al (aluminum) were evident, which indicates that the patches are indeed composed of clay sediments.

## XRD

Although the EDS scans of the seal boss' applied surface revealed that the layer was composed of magnesium silicate (topped-off with a calcium phosphate slip), it was not possible to tell what mineralogical form it took. In order to determine this, as well as to characterize the discolored, seemingly heat-altered sub-surface zone of steatite, samples from the boss were analyzed in December 2009 on the Rigaku Rapid II X-ray diffractometer at the S. W. Bailey X-ray Diffraction Laboratory, Department of Geology and Geophysics, University of Wisconsin–Madison. Using the tip of an X-Acto knife, tiny (sub-millimeter) pieces were removed in three places along the section cut for EMPA

(Appendix 7.15 Figure 12 top left). Sample 1 is a piece of the applied white surface layer. Sample 2 is a piece of the seal's interior removed from a point about halfway down the discolored zone. Sample 3 is a piece of the unaltered interior steatite. The XRD spectra for the three samples are shown on the bottom half of Appendix 7.15 Figure 12.

Sample 1 was X-rayed twice – once on the exterior surface and once on the reverse, sub-surface side (Appendix 7.15 Figure 12 top right two images). Enstatite, well-developed cristobolite and a minor talc phase were detected on the exterior side. On the reverse, sub-surface side of Sample 1, talc was the primary mineral phase detected along with minor phases of cristobolite and enstatite. It is important to note at this point that, although I attempted to remove just the applied surface layer for analysis, some of the underlying steatite of the original seal came off with the sample (notice the light khaki-colored appearance of the sample in the lower of the top right two images in Appendix 7.15 Figure 12). The minor talc phase detected in the spectra of surface XRD scan was almost certainly some of this interior material. Conversely, as the X-ray beam passed through the steatite that adhered to the reverse side of the applied surface, talc was main phase detected. The minor phases of enstatite and cristobalite observed in that scan, in all likelihood, represent the applied talcose surface layer, which is probably composed solely of those two minerals.

The spectrum for Sample 2 indicates that, despite the discoloration of the steatite in this area, the composition of the material is pure talc. Recall from Appendix 7.12 the steatite chips that were fired at 800°C for up to three hours. The appearance of those experimental samples lightened somewhat but XRD analysis indicated that their talc component remained unchanged. The spectrum for Sample 3 – the unaltered khaki-colored raw steatite beneath the lighter zone – is absolutely identical to the spectrum for Sample 2. It therefore appears that below the thin enstatite-cristobolite surface layer the seal is entirely talc.

## CONCLUSION

Although much remains to be learned about the technology and process of Harappan seal manufacture, the EMPA, VP-SEM and XRD observations made here have provided a great deal of information about the surface of this particular seal boss fragment. The carved steatite body of the object is covered by an extremely thin (≈ 20 microns) layer composed of talc that has been heated to a temperature of 1200°C or greater (and, thus, it is no longer talc but rather the minerals enstatite and cristobalite) as well as a calcium phosphate slip. There are several indications that the talcose layer is an applied surface rather than the result of bleaching or in situ heat-treatment. The texture of the layer in section is very distinct when compared to the compact steatite of the seal body and, in certain places, the platy grains of material making it up are oriented in ways that appear as if they flowed in a viscous form into grooves in the seal's carved steatite body. Most importantly, however, it that given the intensity of the cristobolite peaks detected and the extreme thinness of the surface layer in which that mineral phase is found, this transformation could not have taken place in situ. Published analyses (see Wesolowski 1984 for a review of various steatite heating studies) as well as my own experimental work (appendices 7.12 and 7.16; Jamison and Law 2007) demonstrates that it takes temperatures in the range of 1200°C or greater in order to for well-developed cristobolite phases to develop in steatite (weak peaks of cristobolite may develop at temperatures closer to 1100°C). Although heat evidently penetrated the seal body enough to lighten the appearance of the raw steatite to a depth of up to 4 mm immediately below the surface layer, it clearly was not of sufficient intensity or duration

to cause any mineralogical change in that zone (not even minor peaks of enstatite). One centimeter thick chips cut from Daradar deposit samples (the very deposit the INAA studies predicted to be the source of the boss fragment) that were experimentally heated by Gregg Jamison and myself (Jamison and Law 2007) showed that it took 5 minutes at 1100°C for the steatite to be fired completely throughout. Those and other (appendices 7.12 and 7.16) experiments also demonstrated that it takes a considerably longer time and higher temperatures than that for well-developed cristobalite to develop. So what it comes down to is this: If the seal had been exposed to heat of the intensity and duration required for that mineral to form on its surface then the interior would have been altered, at least to enstatite, throughout. It has not been, however. In fact, the XRD analysis showed that talc directly abuts the enstatite-cristobalite layer. Based on these observations, I have concluded that the surface layer is composed of previously high-fired steatite that was ground[1)] (or talc was first ground and then fired) into a fine powder and applied to carved seal's surface.

The calcium phosphate detected on the outer surface of the seal and preserved in a micro-crack within its body is perhaps a bone-ash slip/treatment of some kind that was added after the talcose layer was applied. Bone ash is added to certain kinds of porcelains "as a way of enhancing whiteness, translucency and strength" (Pishch *et al*. 1997: 61). It may have been applied to Harappan seals for those very same purposes.

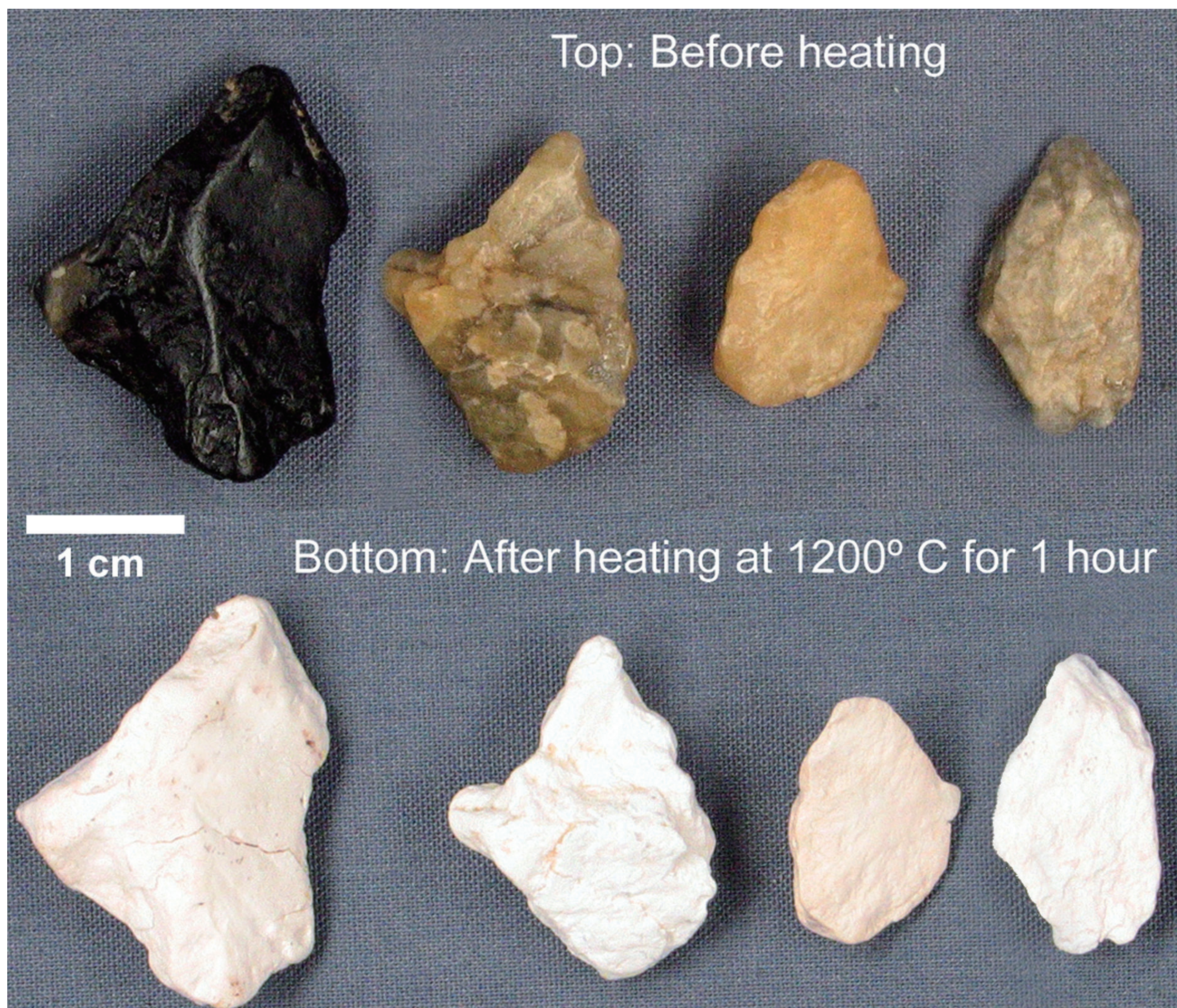
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1) Actually, Harappans had no need to deliberately grind steatite as an abundance of extremely fine powder is produced during the sawing and drilling of that stone. Massimo Vidale believes (2000: 63) that "talc working craftspeople used to live and work surrounded by 'clouds' and mud of white talc powder." Today, the steatite carvers at the shrine of Shah Noorani collect, package and sell this powder (Appendix 7.15 Figure 13) for a variety medicinal uses (Vidale and Shar 1990: 64).

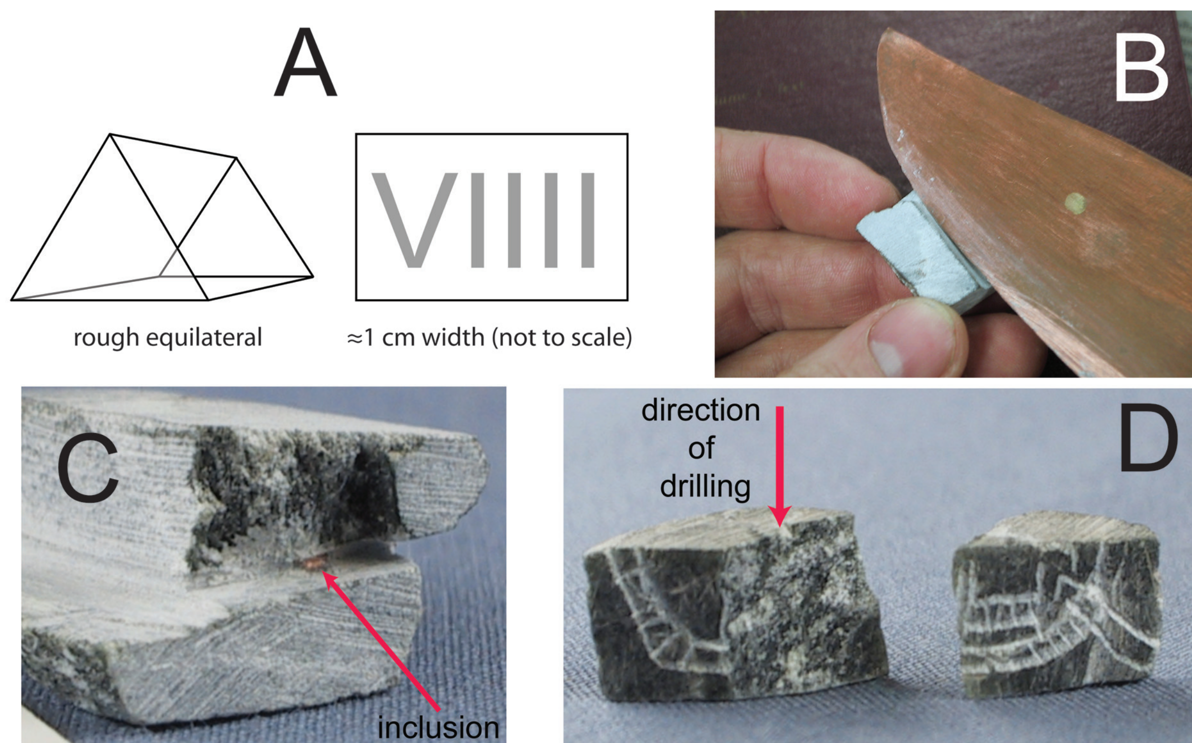
# APPENDIX 7.16

## HEATING AND CHARACTERIZATION OF STEATITE FROM VARIOUS GEOLOGIC SOURCES

Barthélémy de Saizieu and Bouquillon (1994: 51) heated "raw steatite flakes found at Mehrgarh" and observed that their color turned from black to white between 800°C to 900°C. I heat-treated four steatite fragments (unworked and unprovenienced pieces turned in by a workman) from Harappa that were of varying colors including jet black (Appendix 7.16, Figure 1). After a one hour static firing at 1200° C, all four had become bright white, just like the tens of thousand of heat-treated steatite artifacts recovered at the site. That the color of these unfired scraps of raw steatite left behind by Indus Tradition craftspeople should transform in this way is not at all surprising as a white appearance was what was evidently sought when objects made from this variety of stone were fired. The debris from manufacturing such objects should naturally become white also. However, can we conclude that all steatite fires white? In this appendix, I provide an overview of my attempts to answer this question. In addition, I detail the effort to characterize the quality/workability of steatite from different geologic sources in Pakistan and India.




**Appendix 7.16 Figure 1** Experimental heating for four unworked steatite fragments from Harappa (surface finds).

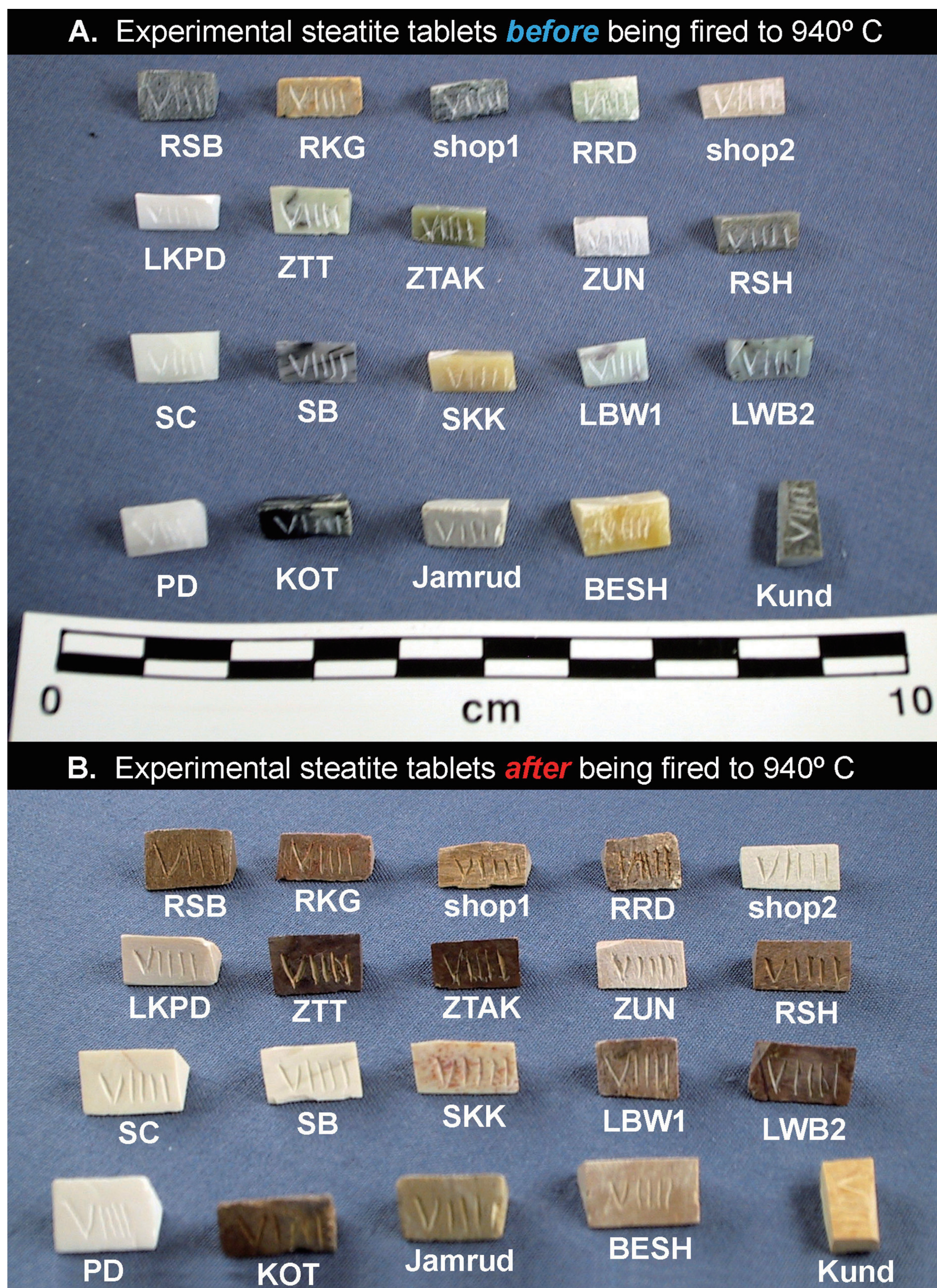



**Appendix 7.16 Figure 2** **[A]** Experimental steatite tablet dimensions. **[B]** Replica copper saw. **[C]** Inclusion in Jamrud (NWFP) deposit steatite. **[D]** A seal replica using Shiv Bola (southern Rajasthan) steatite that split during drilling.

My initial steatite heating and characterization experiments were conducted in the Spring of 2002. At that time, samples from only 20 locations were available for study (these are listed in Appendix 7.16, Figure 4). Sixteen were from steatite sources that would go on to be included in the geologic dataset (their source codes correspond to those used in Chapter 7 and listed in Appendix 7.2). Two others were from sources in Pakistan – Jamrud in the Khyber Agency, FATA and Kund from the Peshawar District, NWFP. Neither of these would be analyzed for the provenience study due, in large part, to the observations reported in this appendix. The final two samples were taken from steatite purchased in shops. Sample "shop 1" was obtained from the workshop of a steatite carver named Ravi Soni in Udaipur, Rajasthan. Sample "shop 2" was purchased from the main bazaar in Attock City, northern Punjab Province, Pakistan.

In order to gauge the quality/workability of the stone from each of the different sources, the blanks to be heat-treated were fashioned into replicas of prism-shaped incised steatite tablets in dimensions (Appendix 7.16, Figure 2 A) approximating those reported in Meadow and Kenoyer (2000). The tablets were cut using a replica of a Harappan period bronze saw (Appendix 7.16, Figure 2 B) that was reconstructed by Dr. J. Mark Kenoyer based on scanning electron microscopy (SEM) studies of steatite debitage (Kenoyer 1997b). The Harappan sign "VIIII" was incised onto one face of each of the tablets using a copper stylus with a beveled end. The 20 completed, unfired replicas can be seen in Appendix 7.16, Figure 3 A.

As is evident on Appendix 7.16, Figure 3 A, not all of the experimental tablets could be carved into prism-like shapes with nice even edges. While many (or most) of the problems had to do, no doubt, with my lack of skill as a carver, much of the difficulty was attributable to the varying quality of raw material from different sources. The heavily foliated steatite from Kund kept splitting. Ultimately the tablet from




**Appendix 7.16 Figure 3** Heating experiment using steatite from 20 South Asian deposits.

**Appendix 7.16 Figure 4** Descriptions of the 20 geologic steatite samples used in the initial heating experiment.

| *Source* | *Parent-Rock* | *Pre-fire color* | *fired color* | *volume change* | *weight change* | *final hardness* |
|---|---|---|---|---|---|---|
| PD | Dolomite | Very light gray N 8 | White N 9 | 9.00% | -1.48% | 6 |
| KOT | Ultramafic | Greenish black 5 G 2/1 to Greenish gray 10 GY 5/2 | Dark yellowish brown 10 YR 4/2 | -5.00% | -3.20% | 5 to 6 |
| Jamrud | Dolomite | Very light gray N 8 | Pale yellowish brown 10 YR 6/2 | 1.75% | -1.44% | 5 |
| BESH | Dolomite | Yellowish gray 5 Y 8/1 | Yellowish gray 5 Y 8/1 | -4.00% | -0.76% | 5 to 6 |
| Kund | Dolomite | Dark greenish gray 5 GY 4/1 | Grayish orange 10 YR 7/4 | n/a | n/a | 5 to 6 |
| SC | Dolomite | Very light gray N 8 | Very light gray N 8 | -0.75% | -2.28% | 6 |
| SB | Dolomite | Med. Light gray N 6 to Dark gray N 3 | White N 9 | -0.75% | -1.49% | 6 |
| SKK | Dolomite | Yellowish gray 5 Y 8/1 | Yellowish gray 5 Y 8/1 | -2.00% | -2.32% | 6 |
| LBW1 | Ultramafic | Very pale green 10 G 8/2 to Med. Dark gray N 4 | Dark yellowish brown 10 YR 4/2 | -2.75% | -2.03% | 5 to 6 |
| LBW2 | Ultramafic | Greenish gray 5 G 6/1 to Black N 1 | Dark yellowish brown 10 YR 4/2 | -0.75% | -2.60% | 6 |
| LKPD | Dolomite | White N 9 | Pinkish gray 5 YR 8/1 | -3.75% | -1.56% | 5 to 6 |
| ZTT | Ultramafic | Light greenish gray 5 G 6/1 to Grayish black N 2 | Dusky yellowish brown 10 YR 2/2 | -13.50% | -2.07% | 6 |
| ZTAK | Ultramafic | Dusky yellow green 5 GY 5/2 | Dusky yellowish brown 10 YR 2/2 | 2.00% | -1.85% | 6 |
| ZUN | Ultramafic | Med. Light gray N 6 | Yellowish gray 5 Y 8/1 | 0.25% | -1.38% | 6 |
| RSH | Ultramafic | Dusky yellow green 5 GY 5/2 to 5 GY 3/2 | Dark yellowish brown 10 YR 4/2 | -2.00% | -2.33% | 5 to 6 |
| RSB | Ultramafic | Dark greenish gray 5 GY 4/1 | Dark yellowish brown 10 YR 4/2 | -12.00% | -3.89% | 5 to 6 |
| RKG | Ultramafic | Grayish orange 10 YR 7/4 to Dark yellowish orange 10 YR 6/6 | Dark yellowish brown 10 YR 4/2 | -11.00% | -2.12% | 5 to 6 |
| Shop1 | unknown | Pale green 5 G 7/2 | Grayish orange pink 5 YR 7/2 | 3.00% | -3.25% | 6 |
| RRD | Ultramafic | Dark greenish gray 5 GY 4/1 to Greenish black 5 GY 2/1 | Grayish orange pink 5 YR 7/2 | 9.00% | -2.46% | 5 to 6 |
| Shop2 | unknown | Grayish orange pink 5 YR 7/2 | Pinkish gray 5 YR 8/1 | 3.75% | -0.47% | 5 to 6 |



**Appendix 7.16 Figure 5** Cracked tablet RRD (post-firing).

that source had to be made flat and rectangular. The Jamrud steatite had a great many quartz inclusions in it that made sawing difficult (Appendix 7.16, Figure 2 C). A rough-looking tablet from that source was shaped only after considerable effort and material waste. Problematic inclusions were encountered in the KOT and "shop 1" samples. Most of the remaining tablets were fairly easily carved and incised. I also attempted to make several rectangular replica seals using stone from various sources. Most also carved fairly well but one from the Shiv Bola deposit of Rajasthan quickly split when I tried to drill a hole through its center (Appendix 7.16, Figure 2 D).

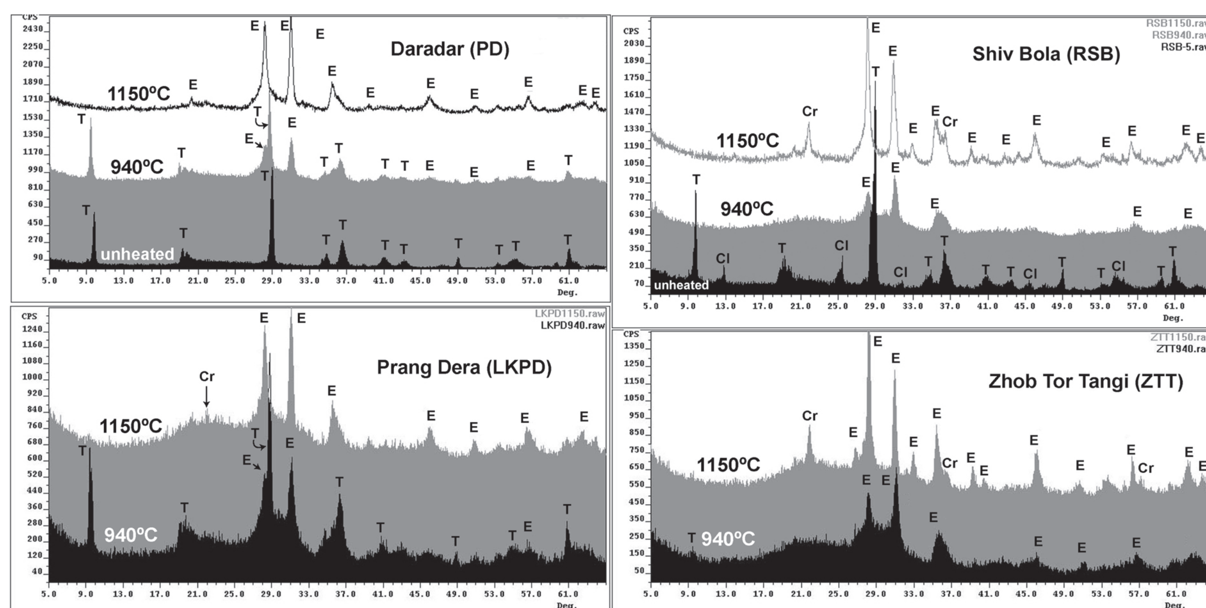
Prior to firing, each of the 20 prism-shaped tablets was weighed, measured and its color characterized using a Munsell Rock Color Chart. The surfaces of all of them could be scratched using a calcite crystal and thus each had a hardness of 2½ or less on the Mohs' Mineral Hardness Scale (Appendix 2.1). They were then placed in a muffle furnace and the temperature was slowly raised 60°C per hour to 940° C. The tablets were held at this temperature for one hour and then the furnace was turned off and allowed to cool slowly overnight. The next day all were re-weighed, measured and color-characterized. The post-firing hardness of the tablets was scratch-tested using apatite (hardness 5), feldspar (hardness 6), quartz (hardness 7).

The post-firing appearance of the incised tablets is pictured in Appendix 7.16, Figure 3 B (the before and after Munsell characterizations are listed in columns three and four of Appendix 7.16, Figure 4). Only five of them (PD, SC, SB, LKPD, ZUN and "shop 2") exhibited a post-firing color that was white (or anything close to it). It is important to note that all but one (SB) of those was white or near-white in appearance to begin with. The color of most of the remaining tablets had become a dull rusty red.

Post-firing changes in volume, weight and hardness for each tablet are listed in the fourth through sixth columns of Appendix 7.16, Figure 4. Most of them held up well physically, meaning that heat-induced changes in weight and volume (due to water being driven off during the conversion of talc to enstatite) did not cause them to split, crack or flake. Only the tablet carved using steatite from RRD (from Rishab-der in southern Rajasthan) exhibited any significant cracking (Appendix 7.16, Figure 5). Mineral scratch tests indicated that the Mohs hardness for most tablets was just around 6 while some fell between 5 and 6.

A series of XRD analyses were performed on select tablets – from PD, LKPD, RSB and ZTT. Each of these was sawn into two pieces, one of which was re-heated to 1150ºC for one hour. No further macroscopic changes were evident after the halves were reheated (i.e, they did not become any whiter) but their hardness increased to between 6 and 7 (PD and LKPD) to 7 (RSB and ZTT). Unheated powder from the carving of tablets PD and RSB was also X-rayed. PD was pure talc to being with but steatite from RSB contained a minor chlorite phase.

Composites of all XRD scans for the three tablets can be seen in Appendix 7.16, Figure 6. In each one, talc had begun to transform into enstatite by 940ºC, although the decomposition/formation of those minerals was different from tablet to tablet. In ZTT, talc had all but disappeared (there is a minor peak at around 9.75º) while in LKPD it was still the dominant mineral. Talc had entirely decomposed in each of the




**Appendix 7.16 Figure 6** XRD scans of heated steatite samples from three sources. Peak Key: T = talc, Cr = cristobalite, E = enstatite, Cl = chlorite.

tablet halves that were heated to 1150ºC. Cristobalite had begun to form in RSB and ZTT as well as, just barely, in LKPD. No cristobalite peaks were evident in the scan for PD, however. The varying Mohs hardness values in the heated samples are attributable to the differential formation of these minerals.

The results of the initial heating experiment indicated several things. First and most importantly, it was quite clear that <u>not all steatite becomes white when it is heat-treated</u>. It was also apparent that mineral composition, inclusions, foliation and bonding of raw steatite were all things that affected the ease to which steatite was carved and, probably, how well it held together when fired. Lastly, the hardness of fired steatite is a function of the temperature to which it was heated (and to a lesser extent how long it was heated). The formation of enstatite will impart a steatite object with a hardness of around 5 to 6. Only those tablets that were re-heated to 1150ºC exhibit a hardness of higher than 6.

Ernest Mackay documented (1933) the ancient process for bleaching white designs onto carnelian beads that involved heat in combination with an alkali-based solution. Upon seeing the results of the initial steatite heating experiment, Dr. J. Mark Kenoyer suggested that I attempt to bleach that stone using the same technique. I agreed to try. Raw steatite from three sources – LBW1, SB and KOT, were cut into three pieces each. These can be seen in the figure below (Appendix 7.16, Figure 7). The pieces labeled "1" are the raw, unfired stones. Those labeled "2" were treated with the carnelian bleaching solution recorded by Mackay. This consisted of sodium carbonate ($Na_2CO_3$) and juice from the "kikar" plant (*Capparis aphylla* – a type of caper native to South Asia) that was carefully mixed and strained. The steatite pieces were allow to soak in this solution for five days after which they were placed (while the exterior was still damp) into the muffle furnace. The temperature was slowly raised 60°C per hour to 1150° C, allowed to dwell there for one hour and then turned off to cool overnight. The pieces on the figure labeled "3" were soaked for five days in a paste of consisting of calcium carbonate ($CaCO_3$ – which Massimo Vidale [2000: 62] has previously suggested might have been used to whiten steatite) and potassium hydroxide (KOH) or "potash," which was added on the suggestion of Dr. Kenoyer. These were heated along with those soaked in the $Na_2CO_3$-kikar solution.

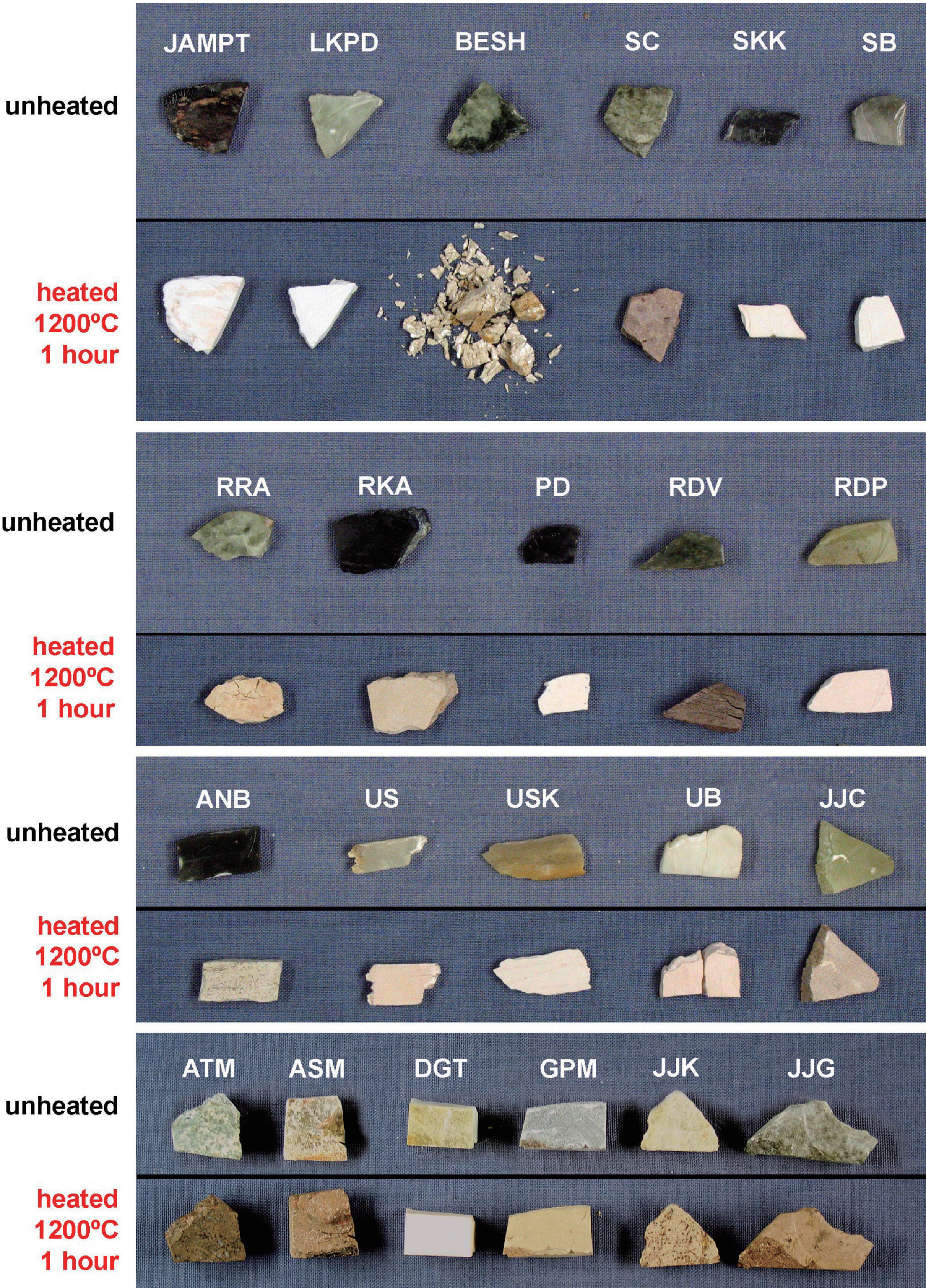



**Appendix 7.16 Figure 7** Experimental heating in combination with bleaching of steatite from three sources. 1 = unfired steatite, 2 = fired after being soaked in sodium carbonate and "kikar" juice, 3 = fired after being soaked in calcium carbonate and potash.

The photograph for Appendix 7.16, Figure 7 was taken after the bleaching/heating experiment was completed. Compare the pieces labeled "2" and "3" on that figure to the post-fired appearance of their corresponding tablets pictured in Appendix 7.16, Figure 3 B. Those from LBW1 and KOT exhibit exactly the same dull red post-fired appearance that they did in the initial heating experiment. The piece from source SB did fire white this time but it also fired white in the initial experiment in which it was untreated. There is nothing to indicate that the two alkali solutions affected any color change in the samples at all. Of course, this does not prove that Indus Tradition craftspeople were incapable of bleaching steatite. I may have incorrectly prepared and/or applied the solutions. However, new data began to come light around the time these experiments were conducted that suggested there was probably little need for Harappans to bleach steatite white.

The results of the provenience study of steatite that are detailed in Chapter 7 indicated that, of the 139 artifacts analyzed from Harappa (I exclude the BMAC wig and the seal boss sample), 138 appear to have been derived from sources of dolomitic origin (see Figure 7.14). An emphasis on the use of this type of raw material was seen at several of the other Indus Tradition sites from which steatite artifacts were analyzed. Furthermore, the majority of the dolomitic steatite artifacts from Harappa and Mohenjo-daro appear to have been derived from a select few deposits in northern Pakistan and India. Of those, samples from PD, LKPD, SB, SC and SKK were heat-treated in the initial experiment (Appendix 7.16, Figure 3). The post-firing appearance of all of them, save for the tablet made from SKK steatite, was white. None of the tablets from ultramafic sources had become that color except for the one from ZUN. That one was white to begin with and was actually became an off-white shade it was fired. So it seemed as if Harappans were very deliberately exploiting white-firing stone from dolomitic while ignoring non-white-firing ultramafic stone. However, except for the stone from SB, all of the white-firing dolomitic samples were also white to begin with. Raw steatite of that color has never been found at Harappa.

It was decided to heat a series of dolomitic steatite samples that, in appearance, were more like the raw material recovered at Harappa, that is – colorful (recall Figure 7.4). At the time I did this




**Appendix 7.16 Figure 8** Experimental firing of steatite chips from select dolomitic sources.

(Fall 2003), samples from 22 dolomitic sources had been obtained. Unfired chips taken from these are pictured in Appendix 7.16, Figure 8 in the rows marked "unheated." These chips were placed in the muffle furnace and the temperature was raised quickly (200°C per hour) to 1200° C and left to dwell for one hour. This time and temperature was sufficient to turn any kind steatite white if it was predisposed to do so.

Post-firing images of the steatite chips are visible in the rows directly beneath the "unheated" ones in Appendix 7.16, Figure 8. The majority of them did not become white after being fired. Most of those that did are from sources in northern Pakistan and India (JAMPT. LKPD, SKK, SB and PD) that were predicted in Chapter 7 to have been ones used by residents of Harappa. Three chips from sources in Uttaranchal and Rajasthan also became white (USK and DGT) or near white (RDP). Although it was not my intent to the examine quality/workability of steatite from different sources, most seem to have held up well in this quicker and hotter firing. Three chips (RRA, RDV and UB) showed signs of cracking and one from BESH exhibited what can only be described as catastrophic failure.

A few important observations can be made as a result of this firing. Firstly, just as it is not possible to say that all steatite fires white it is also not possible to say that all dolomitic steatite fires white. Materials from some sources clearly will not. Moreover, there are good indications that even within individual steatite deposits there are raw materials that fire in different ways. Note that the SC chip did not become white in this last heating experiment but the SC tablet from the initial one did. The JAMPT chip fired bright white in Appendix 7.16, Figure 8 but recent (May 2007) studies with Gregg Jamison (Jamison and Law 2007) using material from that source only produced light grayish-colored results. These observations actually fit well with my suggestion in Chapter 7 that highly compositionally similar groups within the set of steatite artifacts analyzed from Harappa might represent raw materials extracted from a very restricted area *within* an individual occurrence. In order to obtain white-firing stone for their beads and seals, Harappans had to be (and clearly were) highly selective.

# APPENDIX 7.17

# IS IT POSSIBLE TO SOURCE FIRED STEATITE ARTIFACTS USING INAA?

## INTRODUCTION

All of the artifacts characterized using INAA in Chapter 7 are composed of unmodified or "raw" steatite. Once cleaned and desalinated it is, materially speaking, as if the stone has come directly from the source. Harappa, Mohenjo-Daro and Mehrgarh are sites where there were extensive steatite craft activities and, thus, there is an abundance of such raw manufacturing debris that can be sampled for studies of this kind. I have found that most other Harappan settlements are not nearly as rich in this regard, however. For example, out of the tens of thousands of stone artifacts at the Indus city of Dholavira I have recorded only a dozen or so pieces of steatite manufacturing debris. Most site assemblages contain even fewer, if any, such fragments. On the other hand, heat-treated or "fired" steatite beads are found, often by the hundreds or even thousands, at practically every Harappan settlement. If it could be determined from where the raw material used make those beads was derived then it might be possible to identify different production centers and reconstruct, in great detail, distribution networks for beads made from this stone. We might even be able to examine exchange networks between Indus Civilization peoples and the non-Harappan peoples outside of the greater Indus region who have frequently been found to have possessed such beads. But is it possible to source fired steatite artifacts using INAA?[1)]

I thought that it might be. Although heating substantially alters the mineralogical character of steatite (recall Appendices 7.12 and 7.16), other than driving off it's water component the major and, importantly with regard to this study, the trace element composition of the stone should, in theory at least, remain unchanged. If a fired steatite bead were fashioned from a solid piece of stone (rather than a paste that could contain additives) and was unmodified by a bleach, glaze or some other treatment, then analyzing it should produce results roughly the same as analyzing unheated raw material from the same source. This seemed like a plausible scenario so I decided to conduct a small pilot study in order to test it.

My idea for the study was simple. I would heat a set of steatite samples from known deposits that I had been previously characterized using INAA. The heat-treated samples would then be re-characterized and compared, as ungrouped cases (i.e., as if they were of unknown provenience) using canonical discriminant analysis (CDA), to the database of South Asian steatite sources that I had assembled. Relative success would be judged based on what percentage of the fired samples were correctly assigned to the source or source region from which they actually came.

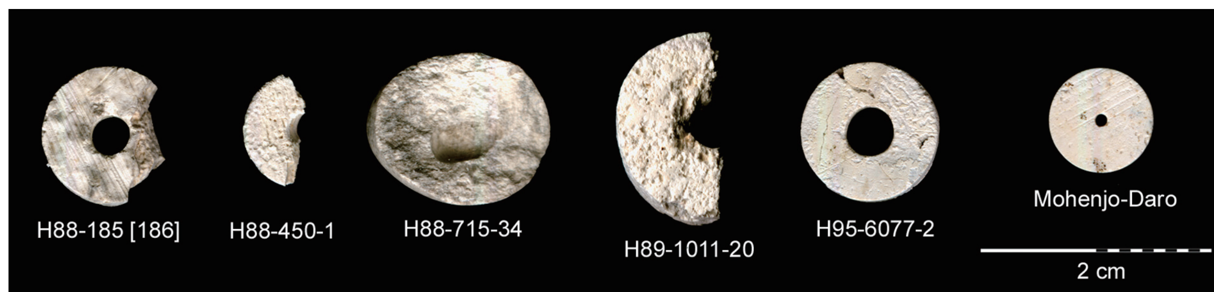
## EXPERIMENTAL HEATING AND INAA

Small chips were cut from twenty steatite samples – two each from ten different deposits – that were previously subjected to INAA. These can be seen in the left-hand image of Appendix 7.17 Figure 1. Each is labeled with a two or three letter code

1) The title and subject of this appendix is the same as a paper I presented at the 38th Conference on South Asia, University of Wisconsin-Madison, October 23–25, 2009.




**Appendix 7.17 Figure 1** Left - A set of chips taken from 20 geologic samples previously subjected to INAA. Right - The same 20 chips after being fired at 1200ºC for one hour.




**Appendix 7.17 Figure 2** The five fired steatite artifacts (beads or bead fragments) from Harappa and one from Mohenjo-Daro subjected to INAA for this pilot study.

that corresponds to sources listed in Appendix 7.2. The letter codes are followed by a sample numbers. These (letter codes + numbers) correspond to the individual samples listed in Appendix 7.3, which is the original INAA results table for the geologic samples. All twenty chips were placed together in a muffle furnace and heated in a single static firing for one hour at 1200ºC. This is long enough and hot enough to produce the mineralogical features (enstatite and cristobalite) exhibited by high-fired Harappan steatite beads (recall Appendix 7.14). The post-firing appearance of the chips can be seen in the right-hand image of Appendix 7.17 Figure 1. It is interesting and important to note that the only geologic samples that became white and/or lightened significantly were those from the Sherwan deposits of the NWFP (source codes SKK, SC and SB), which is the regional occurrence shown in Chapter 7 to have been the major source of steatite for residents of Harappa. After being fired, the 20 chips were prepared and subjected to INAA following the procedures outline in Chapter 3.

Along with the heat-treated geologic samples, five fired steatite beads from Harappa and one from Mohenjo-Daro (Appendix 7.17 Figure 2) were prepared and subjected to INAA. These artifacts were selected from among the thousands that have been recovered during surface surveys at those sites. All had clearly been carved from solid steatite and did not appear to have been glazed. I was interested to learn which deposits they would be predicted to belong when they were compared to the steatite sources database using CDA. Around 95% of the steatite acquired by residents of Harappa appears to have come from sources to the north of the city while most of the remaining 5% was derived from

deposits in northern Rajasthan. At Mohenjo-Daro, the ratio of raw material exploited from those two broad source regions was more like 60% to 40% respectively. If the six steatite beads are predicted to belong to deposits in altogether different regions then that might be an indication that it is not possible to accurately source such artifacts using INAA.

## RESULTS

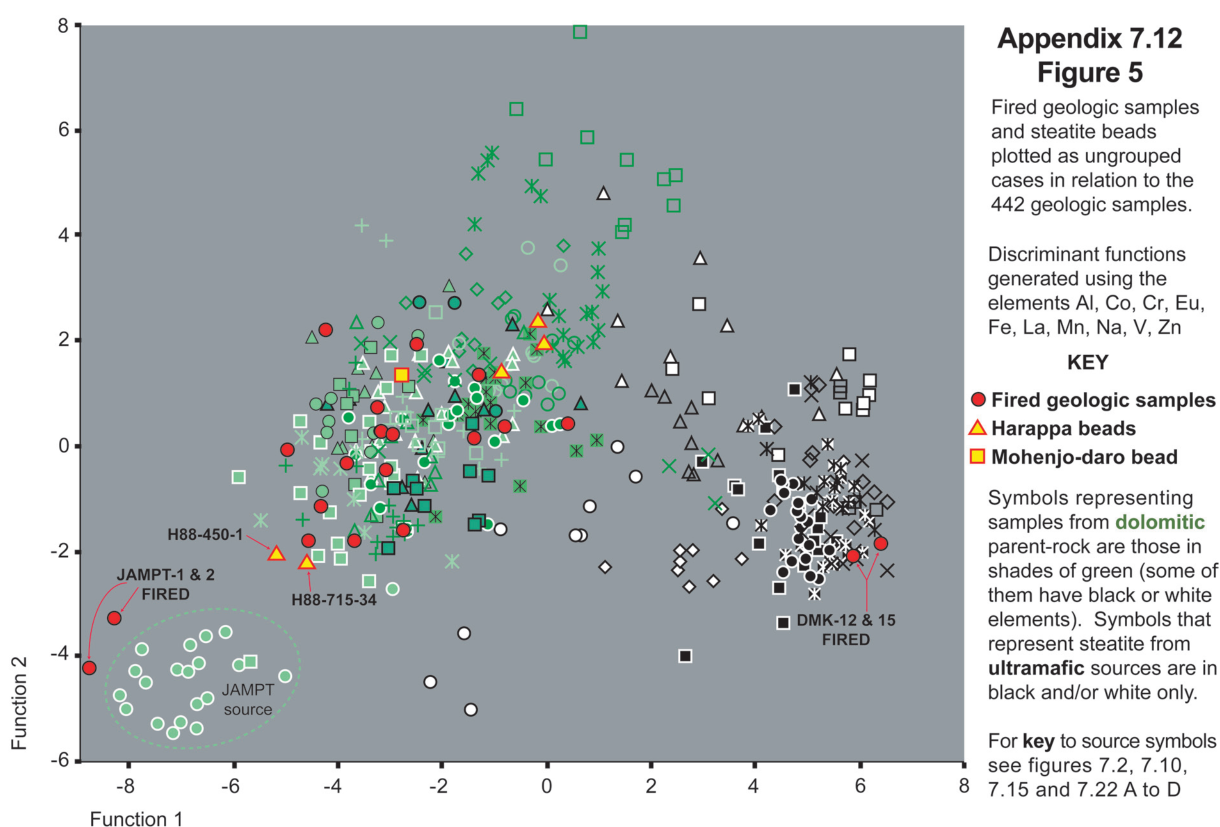
The INAA data for the heat-treated geologic samples are listed in Appendix 7.17 Figure 3 and those for the six steatite beads are listed in Appendix 7.17 Figure 4. Using CDA, these data were compared to the steatite sources database (Appendix 7.3) as ungrouped cases and plotted by their discriminant scores (Appendix 7.17 Figure 5). The heated geologic samples fell on the plot basically where expected. The two fired chips taken from the Dev Mori Kundol (DMK) deposit in northeastern Gujarat, which was the only ultramafic source fired and analyzed, plotted with the large cluster of ultramafic source samples on the right-hand side of the plot. The two fired chips from the Painthal deposit in Jammu (JAMPT) fell close by the distinct cluster of geologic samples from that source.

**Appendix 7.17 Figure 3** INAA data for chips taken from previously analyzed raw steatite samples and then heat-treated. Elemental data in parts per million (PPM).

| Sample | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SKK-11 FIRED | 4341 | 0.76 | 4.03 | 0.023 | 3216 | 0.107 | 7.93 | 159 | 0.255 | 7.85 | 8.4 |
| SKK-8 FIRED | 2266 | 0.833 | 1.76 | 0.032 | 2328 | 2.262 | 7.37 | 187 | 0.116 | 3.82 | 4.75 |
| SC-9 FIRED | 57290 | 3.409 | 36.12 | 0.113 | 8685 | 12.56 | 18.3 | 245 | 2.636 | 42.1 | 25.19 |
| SC-10 FIRED | 1186 | 1.178 | 1.51 | 0.047 | 2447 | 1.598 | 7.49 | 122 | 1.144 | 5.23 | 16.52 |
| SB-5 FIRED | 4899 | 2.281 | 6.24 | 0.069 | 5751 | 1.454 | 8.71 | 140 | 0.297 | 7.48 | 9.43 |
| SB-9 FIRED | 14480 | 0.907 | 8.17 | 0.026 | 4444 | 0.1947 | 8.35 | 149 | 0.324 | 11.75 | 9.81 |
| JAMPT-1 FIRED | 1130 | 0.218 | 0.98 | 0.016 | 9236 | 0.0202 | 7.96 | 119 | 0.029 | 3.27 | 13.07 |
| JAMPT-2 FIRED | 1029 | 0.4 | 1.24 | 0.016 | 14250 | 0.0614 | 14.6 | 221 | 0.024 | 4.06 | 21.26 |
| DMK-12 FIRED | 19090 | 73.75 | 2427 | 0.051 | 41600 | 0.0624 | 398 | 164 | 6.049 | 40.6 | 38.69 |
| DMK-15 FIRED | 6071 | 81.35 | 2139 | 0.042 | 39450 | 0.0251 | 341 | 132 | 6.184 | 30.8 | 38.47 |
| JJK-4 FIRED | 17430 | 3.316 | 31.85 | 0.051 | 24980 | 0.1909 | 83 | 239 | 3.199 | 135.4 | 27.87 |
| JJK-8 FIRED | 12770 | 4.273 | 24.91 | 0.031 | 26060 | 0.1312 | 70.1 | 144 | 2.348 | 113 | 24.29 |
| JJC-6 FIRED | 8281 | 18.07 | 25.02 | 0.644 | 40080 | 3.246 | 173 | 148 | 8.622 | 9.76 | 46.54 |
| JJC-7 FIRED | 2665 | 16.5 | 9.14 | 0.033 | 34340 | 0.224 | 99.4 | 300 | 2.227 | 4.22 | 24.46 |
| ANB-5 FIRED | 3329 | 4.358 | 11.21 | 0.032 | 17550 | 0.2109 | 23.1 | 2846 | 0.402 | 14.7 | 10.96 |
| ANB-10 FIRED | 366.5 | 6.601 | 2.3 | 0.023 | 18870 | 0.0633 | 22.1 | 146 | 0.257 | 18.5 | 9.14 |
| ATM-9 FIRED | 2068 | 2.826 | 20.47 | 0.025 | 29450 | 0.2202 | 23.2 | 229 | 0.923 | 8.21 | 16.01 |
| ATM-10 FIRED | 9041 | 2.187 | 20.06 | 0.051 | 39340 | 0.2848 | 37.8 | 6282 | 0.936 | 4.43 | 17.7 |
| USK-6 FIRED | 1051 | 5.659 | 1.92 | 0.034 | 20280 | 0.0797 | 23.5 | 127 | 0.114 | 3.84 | 35.96 |
| USK-7 FIRED | 8306 | 11.33 | 9.68 | 0.032 | 22880 | 0.1836 | 9.89 | 174 | 0.73 | 8.89 | 27.39 |

**Appendix 7.17 Figure 4** INAA data for fired steatite beads from Harappa and Mohenjo-Daro. Elemental data in parts per million (PPM)

| Artifact | Al | Co | Cr | Eu | Fe | La | Mn | Na | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Harappa H95-6077-2 | 1111 | 2.681 | 8.81 | 0.0576 | 3028 | 0.719 | 87.53 | 1401 | 0.2118 | 6.5 | 44.22 |
| Harappa H89-1011-20 | 6454 | 1.553 | 5.81 | 0.0864 | 5136 | 1.084 | 37.13 | 9259 | 0.436 | 5.68 | 14.38 |
| Harappa H88-715-34 | 2514 | 0.482 | 12.27 | 0.0271 | 7045 | 0.119 | 9.29 | 1075 | 0.1157 | 6.06 | 39.55 |
| Harappa H88-450-1 | 1106 | 0.705 | 84.54 | 0.1035 | 13680 | 0.563 | 47.22 | 1734 | 0.1233 | 13.08 | 127.4 |
| Harappa H88-185[186] | 1243 | 3.235 | 8.18 | 0.1256 | 3483 | 3.471 | 94.67 | 2979 | 0.1679 | 4.19 | 44.56 |
| Mohenjo-Daro Disc-bead | 1410 | 0.569 | 12.33 | 0.1277 | 3534 | 0.18 | 42.52 | 4325 | 0.556 | 16.5 | 23.84 |




**Appendix 7.12 Figure 5**

Fired geologic samples and steatite beads plotted as ungrouped cases in relation to the 442 geologic samples.

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, V, Zn

Symbols representing samples from **dolomitic** parent-rock are those in shades of green (some of them have black or white elements). Symbols that represent steatite from **ultramafic** sources are in black and/or white only.

For **key** to source symbols see figures 7.2, 7.10, 7.15 and 7.22 A to D

The remaining heat-treated geologic samples fell among the large cluster of dolomitic steatite source samples in the upper middle potion of the plot. The six steatite beads from Harappa and Mohenjo-Daro also plotted among this cluster, which, at this level of analysis, clearly indicates that these ornaments were each fashioned out of stone from a dolomitic source.

The first and second predicted group memberships (PGMs) generated by CDA for the heat-treated chips are listed in the second and third columns of Appendix 7.17 Figure 6. The fourth column heading of that figure is labeled "1st PGM spot on," which means that the fired geologic samples noted with an "X" in the column below had PGMs in the exact deposits from which they were taken. For example, the first PGM of chip SB-5 was the Sherwan-Banda (SB) deposit. Nine of the 20 samples, or 45%, had "spot on" PGMs. The next column is labeled "1st PGM regionally correct." This means that those fired samples noted with an "X"

**Appendix 7.17 Figure 6** Predicted group memberships (PGMs) of the 20 fired geologic samples.

| Sample | 1st PGM | 2nd PGM | 1st PGM spot on | 1st PGM regionally correct | 1st or 2nd PGM correct |
|---|---|---|---|---|---|
| SKK-11 FIRED | SB | JJK | | X | X |
| SKK-8 FIRED | SC | SKK | | X | X |
| SC-9 FIRED | JJG | UB | | | |
| SC-10 FIRED | US | SC | | | X |
| SB-5 FIRED | SB | SC | X | X | X |
| SB-9 FIRED | SB | PD | X | X | X |
| JAMPT-1 FIRED | JAMPT | JJK | X | X | X |
| JAMPT-2 FIRED | JAMPT | ATM | X | X | X |
| DMK-12 FIRED | DMK | RSB | X | X | X |
| DMK-15 FIRED | DMK | RSB | X | X | X |
| JJK-4 FIRED | JJK | JJG | X | X | X |
| JJK-8 FIRED | JJK | JJG | X | X | X |
| JJC-6 FIRED | UB | RDP | | | |
| JJC-7 FIRED | DGT | ZTAK | | | |
| ANB-5 FIRED | ATM | ANB | | X | X |
| ANB-10 FIRED | JJK | US | | X | X |
| ATM-9 FIRED | JJK | ATM | | X | X |
| ATM-10 FIRED | ATM | ANB | X | X | X |
| USK-6 FIRED | JJK | USK | | | X |
| USK-7 FIRED | PD | USK | | | X |
| percentage of 20 samples correct | | | 45% | 70% | 85% |

in the column had a PGM in a deposit that is in the same related geologic source region from which the raw material it is composed of derived. For example, fired sample SKK-8 is from the Sherwan-Khanda Khu deposit but was predicted to belong to the Sherwan-Chelethar (SC) deposit, which is in the same zone of dolomitic steatite mineralization just a few kilometers away. Fourteen of the 20 samples, or 70%, had "regionally correct" PGMs. Because some of the samples selected for firing could have been compositional outliers of the deposits from which they came (and, thus, potentially misassigned [given a 1st PGM] to a compositionally similar deposit in another region), I decided to include in Appendix 7.17 Figure 6 a sixth column that included the second PGM of samples along with the first. By doing this, I hoped to catch some of those potential outliers. Seventeen of the 20 samples, or 85%, had either their "1st or 2nd PGM correct." The remaining three fired samples were assigned first and second PGMs in sources that, other than being dolomitic, had no geologic relation to the deposit from which they actually derived.

At first glance, the results of the CDA comparison of the heat-treated geologic samples to the steatite source database appear mediocre at best. It seems that slightly less than half the time you can expect to correctly determine the exact deposit from which a fired steatite object came. Just over two-thirds of the time you might be able to assign such an artifact to a regionally correct source. If you decide to take second PGMs into consideration then it might be possible to push the number of correctly assigned artifacts to 85%, which is not great but it is respectable. Although these results seem less than outstanding, it is important to note

**Appendix 7.17 Figure 7** Predicted group memberships (PGMs) of the original geologic samples prior to heat-treatment.

| Sample | 1st PGM | 2nd PGM | 1st PGM spot on | 1st PGM regionally correct | 2nd PGM correct |
|---|---|---|---|---|---|
| SKK-11 RAW | SKK | UB | X | X | X |
| SKK-8 RAW | SC | SKK | | X | X |
| SC-9 RAW | SB | SKK | | X | X |
| SC-10 RAW | US | SB | | | X |
| SB-5 RAW | SC | SKK | | X | X |
| SB-9 RAW | SKK | SC | | X | X |
| JAMPT-1 RAW | JAMPT | USK | X | X | X |
| JAMPT-2 RAW | RSA | USK | | | |
| DMK-12 RAW | DMK | KOT | X | X | X |
| DMK-15 RAW | DMK | RSH | X | X | X |
| JJK-4 RAW | JJK | JJG | X | X | X |
| JJK-8 RAW | JJK | JJG | X | X | X |
| JJC-6 RAW | JJG | RDP | | X | X |
| JJC-7 RAW | JJG | RDP | | X | X |
| ANB-5 RAW | ANB | ATM | X | X | X |
| ANB-10 RAW | JJK | ANB | | | |
| ATM-9 RAW | ATM | JJK | X | X | X |
| ATM-10 RAW | ATM | ANB | X | X | X |
| USK-6 RAW | USK | RSA | X | X | X |
| USK-7 RAW | USK | UB | X | X | X |
| percentage of 20 samples correct | | | 55% | 85% | 90% |

that the fired samples were compared to the entire source database and there significant overlap between certain deposits. Recall that the overall "leave-one-out" cross validation success rate at this level ("full set") of analysis was 69%. This is certainly much better than the 45% "spot on" success rate I got but it based on the cross validation of a substantially more diverse set of geologic samples. There is, however, the possibility that is being explored in this appendix – the heat-treatment of the 20 samples may altered their chemical compositions enough to affect their PGMs. In order to judge that possibility, I went back to the original database of geologic samples and compared the INAA data for same 20 samples prior to them being fired to the "full set" database. Those results are in Appendix 7.17 Figure 7. This time the "spot on" success rate was 55%, the "regionally correct" rate was 85%, and the "1st or 2nd correct" combined was 90%. This is better in all instances but not substantially different and still not perfect. These reason that the PGMs made in the INAA study of unfired steatite artifacts presented in Chapter 7 were

**Appendix 7.17 Figure 8** First and second predicted group memberships (PGMs) for fired steatite beads from Harappa and Mohenjo-Daro.

| Sample | 1st PGM | 2nd PGM |
|---|---|---|
| H88-185[186] | ANB | JJC |
| H88-450-1 | ATM | JJK |
| H88-715-34 | ATM | JAMPT |
| H89-1011-20 | ATM | ANB |
| H95-6077-2 | JJC | ANB |
| MD disc bead | ATM | ANB |

convincing is because there was an overall consistency in their patterning over the large artifact set and throughout multiple scales of comparison. Only six steatite beads have been analyzed at this point. It may require the analysis of many more such artifacts before the same convincing patterns become obvious for fired steatite objects.

The INAA data for the five fired steatite beads from Harappa and one from Mohenjo-Daro were first compared to the full set of geologic samples and then to a set comprised of the dolomitic steatite deposits. The PGMs for these two analyses are listed in Appendix 7.17 Figure 8. Both sets of results are almost identical. In the "full set" analysis a single bead from Harappa (H88-715-34) had a second PGM in the Painthal deposit of Jammu (JAMPT) but in the "dolomitic sources only" analysis the second PGM for the same bead was the Kho deposit in the Jhunjhunu District (JKK) of northern Rajasthan. Otherwise, in every other instance, both the first and second PGMs of the beads were northern Rajasthan sources. These findings do not leave a lot of room for alternate interpretations. That is, if all or many had second PGMs in the one of the Sherwan deposits for example, then I could, perhaps, argue that they were compositional outliers of those deposits. It is not possible to do that, however. Two of the beads from Harappa (H88-715-34 and H88-450-1) do plot on Appendix 7.17 Figure 5 apart from the other four beads in an area where Shewan assigned raw steatite artifacts tend to plot as well. But this is not enough to disregard their assigned PGMs and say they actually belong to the Sherwan zone. The beads' PGMs are based their distances to the various groups' centroids in multi-dimensional space. In Appendix 7.17 Figure 5 we are only seeing two dimensions (discriminant functions 1 and 2). If a multi-dimensional "cloud" of datapoints were viewable then the PGMs assignments for the two beads would likely make more sense visually. In any case, the results strongly suggest that all six beads were made from steatite that was acquired from deposits in northern Rajasthan

So what does this mean? Well, the INAA study presented in Chapter 7 did indicate that raw steatite from the deposits of northern Rajasthan was being acquired by residents of both Harappa and Mohenjo-Daro. So in this regard the findings are consistent with the patterns of source area exploitation at those sites. Based the limited study of Mohenjo-Daro steatite fragments there was roughly a 40% chance that the disc bead from that site would be made from northern Rajasthan stone. Its PGM is, therefore, not difficult to accept. However, the fact that all five of the beads from Harappa were also predicted to be from northern Rajasthan deposits causes me to view those results, while with not skepticism, at with least caution. Fewer than 5% of the 141 raw steatite

fragments and artifacts analyzed from Harappa were attributable to those sources. Detecting a single example made from northern Rajasthan steatite among the beads was, for that reason, statistically unlikely. Having all five predicted to come from that source area is then very unusual. Of course, it could be a mere matter of chance that the five randomly selected artifacts happened to be made of the same, much more infrequently used raw material. The analysis of a larger set of fired steatite artifacts from Harappa should help to determine if that is the case or if the results represent a genuine pattern of raw material use.

Another aspect of the results that gave me pause was that none of the experimental chips of northern Rajasthan steatite fired white. The six beads from Harappa and Mohenjo-Daro clearly could not have been made by only heat-treating raw materials like the ones I sampled from deposits across that region. Those materials would have needed to be bleached or by some other process whitened and this would have, presumably, altered their chemical compositions. This finding does not is not necessarily rule out northern Rajasthan as a Harappan steatite source area, however. The deposits I visited in that region were all recently abandoned mines. All high-quality material had been removed and I was left with only poor-to-mediocre quality stone to sample. Even so, it is likely that white-firing steatite existed at these or related locations in the region at some point in the past.

## CONCLUSION

The answer to the question posed in the title of this appendix is a qualified yes, it is probably possible to source fired steatite artifacts using INAA. Although the success rate for correctly classifying the experimentally heated geologic samples was not what I had hoped it would be, in light of the overall cross-validation success rate for the raw steatite artifact provenience study, it is not too bad, especially on the regional level. I cautiously accept the results of the artifact pilot study, which suggests that the fired steatite beads from Harappa and Mohenjo-Daro were made from raw material that originated in northern Rajasthan.

# APPENDIX 8.1

# INAA DATA FOR AGATE SAMPLES FROM RATANPUR, GUJARAT

Data in parts per million (PPM)

| sample | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|
| GRTP-01 | 1850 | 0.5172 | 10.935 | 0.0799 | 2902 | 0.0812 | 174 | 0.3827 | 0.0517 | 2.12 |
| GRTP-02 | 3401 | 0.7281 | 11.944 | 0.1589 | 2997 | 0.6739 | 187 | 1.1616 | 0.8657 | 13.43 |
| GRTP-03 | 2971 | 0.6626 | 9.104 | 0.1173 | 2532 | 0.2722 | 313 | 0.7013 | 0.3903 | 6.644 |
| GRTP-04 | 2645 | 0.3994 | 8.081 | 0.1026 | 2190 | 0.115 | 350 | 0.6715 | 0.4669 | 6.21 |
| GRTP-05 | 2235 | 0.3284 | 3.402 | 0.0729 | 974 | 0.0065 | 243 | 0.3304 | 0.0499 | 1.331 |
| GRTP-06 | 1501 | 0.5769 | 6.972 | 0.0948 | 1996 | 0.1841 | 142 | 0.4123 | 0.2103 | 3.30 |
| GRTP-07 | 1896 | 0.3891 | 5.328 | 0.0503 | 1210 | 0.0638 | 100 | 0.4977 | 0.0725 | 1.537 |
| GRTP-08 | 3378 | 0.9297 | 15.977 | 0.1438 | 4353 | 0.7066 | 202 | 0.2559 | 0.8286 | 9.192 |
| GRTP-09 | 1924 | 0.3305 | 4.592 | 0.067 | 1234 | 0.0896 | 200 | 0.529 | 0.0272 | 1.557 |
| GRTP-10 | 2113 | 0.4627 | 3.878 | 0.0707 | 1913 | 0.113 | 189 | 0.469 | 0.1628 | 3.037 |
| GRTP-11 | 1852 | 0.4095 | 5.724 | 0.0827 | 1531 | 0.1084 | 202 | 0.5406 | 0.0257 | 1.654 |
| GRTP-12 | 2250 | 0.6177 | 6.852 | 0.0838 | 2306 | 0.0639 | 177 | 0.2773 | 0.5736 | 4.328 |
| GRTP-13 | 1984 | 0.248 | 0.679 | 0.0428 | 317 | 0.113 | 197 | 0.4413 | 0.0126 | 1.304 |
| GRTP-14 | 1747 | 0.1183 | 0.954 | 0.0401 | 139 | 0.013 | 49 | 0.2171 | 1.5517 | 0.916 |
| GRTP-15 | 2070 | 0.3017 | 11.942 | 0.0548 | 1052 | 0.0867 | 127 | 0.2432 | 0.0948 | 3.092 |
| GRTP-16 | 2301 | 0.3953 | 0.804 | 0.0441 | 375 | 0.0555 | 263 | 0.5963 | 0.4464 | 1.082 |
| GRTP-17 | 2559 | 0.3455 | 0.938 | 0.0466 | 604 | 0.1011 | 323 | 0.2978 | 0.2451 | 2.875 |
| GRTP-18 | 2692 | 0.8421 | 12.279 | 0.0618 | 5875 | 0.165 | 162 | 0.1217 | 0.856 | 23.252 |
| GRTP-19 | 2637 | 0.3066 | 0.906 | 0.0353 | 124 | 0.0384 | 469 | 0.171 | 0.2384 | 0.827 |
| GRTP-20 | 1962 | 0.2064 | 3.774 | 0.0262 | 490 | 0.0788 | 99 | 0.0821 | 0.1758 | 1.101 |

# APPENDIX 8.2

# INAA DATA FOR AGATE SAMPLES FROM MARDAK BET, GUJARAT

Data in parts per million (PPM)

| sample | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|
| GMB-01 | 1868 | 0.4005 | 3.56 | 0.0829 | 860 | 0.2008 | 337 | 0.1445 | 0.617 | 1.208 |
| GMB-02 | 1906 | 0.3403 | 6.861 | 0.0571 | 1664 | 0.0868 | 351 | 0.3705 | 0.0597 | 2.009 |
| GMB-03 | 1960 | 0.3792 | 4.576 | 0.0815 | 1194 | 0.1086 | 404 | 0.2321 | 0.0265 | 1.614 |
| GMB-04 | 2287 | 0.3765 | 2.704 | 0.0976 | 543 | 0.5745 | 392 | 0.1494 | 6.4109 | 0.833 |
| GMB-05 | 1992 | 0.5975 | 7.095 | 0.0802 | 1788 | 0.1391 | 528 | 0.4998 | 0.8002 | 2.258 |
| GMB-06 | 2014 | 0.3433 | 5.507 | 0.0495 | 1677 | 0.2123 | 379 | 0.1427 | 6.9568 | 0.958 |
| GMB-07 | 2101 | 0.3493 | 4.339 | 0.1207 | 1048 | 0.5624 | 441 | 0.1298 | 0.0698 | 0.965 |
| GMB-08 | 2052 | 0.6978 | 4.663 | 0.0733 | 957 | 0.2293 | 507 | 0.3478 | 4.678 | 0.927 |
| GMB-09 | 2291 | 0.7152 | 10.936 | 0.0919 | 2501 | 0.2803 | 575 | 0.1863 | 0.4679 | 3.368 |
| GMB-10 | 2010 | 0.4439 | 5.695 | 0.0453 | 1267 | 0.2117 | 370 | 0.6212 | 5.307 | 1.276 |
| GMB-11 | 2058 | 0.4207 | 5.094 | 0.0754 | 1321 | 0.1195 | 331 | 0.6476 | 0.101 | 2.742 |
| GMB-12 | 1917 | 0.4063 | 8.021 | 0.0700 | 1712 | 0.006 | 319 | 0.3900 | 0.0638 | 2.297 |
| GMB-13 | 2305 | 0.1207 | 1.476 | 0.0534 | 213 | 0.9033 | 570 | 0.6653 | 4.9204 | 1.319 |
| GMB-14 | 1946 | 0.1867 | 1.24 | 0.0376 | 260 | 0.117 | 434 | 1.4944 | 3.7008 | 0.060 |
| GMB-15 | 3426 | 0.4849 | 1.762 | 0.0250 | 2626 | 0.1205 | 572 | 0.0496 | 0.5073 | 9.910 |
| GMB-16 | 6360 | 1.4611 | 3.647 | 0.0790 | 3597 | 0.5723 | 1551 | 0.2252 | 1.3634 | 14.253 |
| GMB-17 | 3806 | 0.6573 | 1.805 | 0.0374 | 7683 | 0.3522 | 879 | 0.0040 | 0.311 | 15.854 |
| GMB-18 | 7844 | 1.4600 | 12.873 | 1.4685 | 4735 | 11.3524 | 1787 | 0.1413 | 3.9293 | 40.162 |
| GMB-19 | 2394 | 0.2484 | 2.945 | 0.0400 | 822 | 0.3356 | 477 | 0.1104 | 3.926 | 1.390 |
| GMB-20 | 2567 | 0.1867 | 3.117 | 0.0178 | 773 | 0.0688 | 629 | 0.2699 | 0.1194 | 1.344 |

# APPENDIX 8.3

# INAA DATA FOR AGATE SAMPLES FROM KHANDEK, GUJARAT

Data in parts per million (PPM)

| sample | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|
| GKK-01 | 1907 | 0.1946 | 0.284 | 0.0175 | 99 | 0.0065 | 165 | 0.1555 | 0.0296 | 0.934 |
| GKK-02 | 1828 | 0.6039 | 0.833 | 0.0623 | 418 | 0.7129 | 78 | 0.0306 | 0.1315 | 0.942 |
| GKK-03 | 3295 | 1.9164 | 6.802 | 0.1652 | 1590 | 0.8768 | 373 | 0.8363 | 0.4134 | 6.583 |
| GKK-04 | 1747 | 0.4720 | 0.771 | 0.0269 | 236 | 0.0078 | 100 | 0.8305 | 0.0217 | 1.026 |
| GKK-05 | 2324 | 0.4518 | 0.778 | 0.0313 | 365 | 0.0079 | 337 | 1.0483 | 0.0514 | 1.155 |
| GKK-06 | 1955 | 0.4812 | 0.732 | 0.0550 | 489 | 0.3148 | 167 | 0.1913 | 0.0914 | 0.998 |
| GKK-07 | 1910 | 0.7033 | 1.625 | 0.0799 | 595 | 0.4479 | 209 | 0.6103 | 0.0670 | 1.029 |
| GKK-08 | 1766 | 0.2286 | 1.010 | 0.0227 | 149 | 0.1082 | 90 | 0.1865 | 0.0146 | 0.915 |
| GKK-09 | 1985 | 0.2501 | 0.667 | 0.0284 | 223 | 0.0099 | 184 | 0.2774 | 0.0390 | 0.771 |
| GKK-10 | 2520 | 0.7402 | 0.979 | 0.0336 | 1043 | 0.1650 | 304 | 0.1318 | 0.3259 | 2.624 |
| GKK-11 | 2293 | 0.5263 | 0.818 | 0.0290 | 636 | 0.2094 | 334 | 0.2622 | 0.0990 | 1.943 |
| GKK-12 | 3317 | 0.5683 | 1.032 | 0.0252 | 1048 | 0.2047 | 641 | 0.0836 | 0.4024 | 3.307 |
| GKK-13 | 3482 | 0.4799 | 0.625 | 0.0814 | 974 | 0.7775 | 659 | 0.0988 | 0.1929 | 2.105 |
| GKK-14 | 2322 | 0.1029 | 0.270 | 0.0241 | 90 | 0.0930 | 363 | 1.1208 | 0.0074 | 0.060 |
| GKK-15 | 2351 | 0.2027 | 0.475 | 0.0530 | 300 | 0.6555 | 325 | 0.2968 | 0.0473 | 1.057 |
| GKK-16 | 1963 | 0.1583 | 0.245 | 0.0173 | 138 | 0.0563 | 200 | 0.4982 | 0.0162 | 1.010 |
| GKK-17 | 2900 | 0.7813 | 1.032 | 0.0485 | 988 | 0.3550 | 271 | 0.0588 | 0.2051 | 6.838 |
| GKK-18 | 2064 | 0.8594 | 1.745 | 0.0231 | 1080 | 0.3374 | 301 | 0.1531 | 0.1952 | 4.384 |
| GKK-19 | 2727 | 0.4311 | 0.677 | 0.0329 | 647 | 0.1992 | 348 | 0.6055 | 0.1841 | 3.354 |
| GKK-20 | 2338 | 0.4700 | 1.029 | 0.0256 | 907 | 0.2174 | 335 | 0.3701 | 0.0860 | 2.293 |

# APPENDIX 8.4

# INAA DATA FOR AGATE ARTIFACTS FROM SHAHR-I-SOKHTA, IRAN

Data in parts per million (PPM)

| sample | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|
| S-i-S_01 | 2409 | 0.5995 | 5.404 | 0.0718 | 5013 | 0.6939 | 632 | 3.4254 | 0.2027 | 0.754 |
| S-i-S_02 | 2005 | 0.5482 | 7.577 | 0.0712 | 2099 | 1.9471 | 475 | 2.9873 | 0.1325 | 2.097 |
| S-i-S_03 | 2159 | 0.3412 | 5.310 | 0.0736 | 1367 | 0.4809 | 469 | 3.0094 | 0.0965 | 1.482 |
| S-i-S_04 | 3799 | 0.3242 | 7.035 | 0.0793 | 2584 | 2.6748 | 1172 | 2.9185 | 0.3235 | 1.169 |
| S-i-S_05 | 1761 | 0.3868 | 5.303 | 0.0471 | 2263 | 0.2711 | 415 | 1.8996 | 0.0801 | 0.908 |
| S-i-S_06 | 1834 | 0.5544 | 7.959 | 0.0785 | 2666 | 3.1115 | 602 | 4.1397 | 0.1636 | 2.304 |
| S-i-S_07 | 2015 | 0.3247 | 4.248 | 0.0430 | 1753 | 0.5431 | 574 | 2.6235 | 0.1795 | 1.828 |
| S-i-S_08 | 1692 | 0.3087 | 4.121 | 0.0537 | 1193 | 1.8038 | 648 | 1.5142 | 0.0324 | 1.535 |
| S-i-S_09 | 1837 | 0.2828 | 4.240 | 0.0818 | 1139 | 1.4178 | 463 | 1.6454 | 0.0906 | 0.916 |
| S-i-S_10 | 1704 | 0.2969 | 4.016 | 0.0650 | 1217 | 0.6882 | 242 | 1.7668 | 0.0868 | 1.121 |
| S-i-S_11 | 1863 | 0.4209 | 7.320 | 0.0582 | 1634 | 0.3332 | 950 | 0.5608 | 0.0600 | 1.592 |
| S-i-S_12 | 1662 | 0.4611 | 9.765 | 0.0766 | 1929 | 0.1483 | 593 | 4.427 | 0.0562 | 1.364 |
| S-i-S_13 | 1611 | 0.2977 | 3.950 | 0.0617 | 790 | 0.1098 | 1037 | 2.6625 | 0.0360 | 0.930 |
| S-i-S_14 | 1911 | 0.3488 | 4.835 | 0.0626 | 1100 | 0.1263 | 747 | 0.3519 | 0.0938 | 0.927 |

# APPENDIX 8.5

## INAA DATA FOR AGATE ARTIFACTS FROM HARAPPA

Data in parts per million (PPM).

| sample | Artifact # | Site location | Period | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AH-1 | HM-2397 | unknown | unknown | 1863 | 0.1323 | 0.381 | 0.0015 | 341 | 0.6693 | 517 | 0.2701 | 0.2998 | 0.934 |
| AH-2 | HM-12414 | unknown | unknown | 1814 | 0.1143 | 0.457 | 0.0214 | 585 | 0.2731 | 622 | 0.2938 | 0.0149 | 1.295 |
| AH-3 | H90/3011-154 | survey, Mound E | S&D | 3186 | 0.3578 | 1.246 | 0.0574 | 636 | 0.0722 | 999 | 0.1714 | 0.0168 | 1.564 |
| AH-4 | H90/3011-153 | survey, Mound E | S&D | 3274 | 0.4720 | 2.504 | 0.0628 | 1233 | 0.0961 | 732 | 0.1073 | 0.2342 | 1.294 |
| AH-5 | H90/3030-87 | Tr. 58, Mound E | S&D | 2070 | 0.3554 | 2.562 | 0.0733 | 921 | 0.1679 | 420 | 0.3633 | 0.0453 | 1.209 |
| AH-6 | H90/3037-63 | Tr. 58, Mound E | S&D | 1936 | 0.3948 | 5.633 | 0.0750 | 1449 | 0.1111 | 469 | 0.2651 | 0.1820 | 2.150 |
| AH-7 | H90/3122-12 | Tr. 58, Mound E | Period 3B | 2053 | 0.1341 | 0.381 | 0.0203 | 171 | 0.0329 | 344 | 0.1725 | 0.0199 | 0.818 |
| AH-8 | H90/3070-6 | Tr. 58, Mound E | S&D | 6576 | 1.9976 | 5.360 | 0.0554 | 3426 | 2.2976 | 1321 | 0.3103 | 1.3337 | 13.607 |
| AH-9 | H90/3048-505 | Tr. 58, Mound E | S&D | 1997 | 0.5095 | 4.363 | 0.0669 | 1578 | 0.0723 | 837 | 0.6152 | 0.0378 | 1.976 |
| AH-10 | H90/3068-19 | Tr. 58, Mound E | S&D | 1983 | 0.4604 | 5.100 | 0.0759 | 1839 | 0.1258 | 599 | 0.2579 | 0.0997 | 1.519 |
| AH-11 | H90/3072-1 | Tr. 58, Mound E | Period 3C | 2115 | 0.3336 | 3.815 | 0.0805 | 1269 | 0.2167 | 392 | 0.2629 | 0.0618 | 0.978 |
| AH-12 | H90/3200-36 | Tr. 59, Mound E | S&D | 1741 | 0.3147 | 1.993 | 0.0512 | 605 | 0.0243 | 917 | 0.2766 | 0.0399 | 0.892 |
| AH-13 | H90/3257-20 | Tr. 58, Mound E | S&D | 1889 | 0.3713 | 4.390 | 0.0603 | 1244 | 0.1735 | 683 | 0.2784 | 0.0552 | 2.921 |
| AH-14 | H90/3124-13 | Tr. 56, Mound E | Period 3B | 2552 | 1.0451 | 6.319 | 0.0359 | 3466 | 0.1431 | 459 | 0.2230 | 0.2133 | 19.490 |
| AH-15 | H90/3048-506 | Tr. 58, Mound E | S&D | 3036 | 0.5456 | 0.748 | 0.0438 | 1107 | 0.1264 | 960 | 0.6165 | 0.2289 | 3.300 |
| AH-16 | H88/353-3 | Tr. 51 | Period 3C | 1869 | 0.1512 | 1.001 | 0.0262 | 153 | 0.0345 | 973 | 0.2746 | 0.0734 | 1.806 |
| AH-17 | H88/715-47 | Tr. 52 | Period 3C | 1730 | 0.1238 | 0.921 | 0.0229 | 158 | 0.0248 | 625 | 0.1568 | 0.0369 | 0.970 |
| AH-18 | H88/725-22 | Tr. 52 | Period 3C | 2028 | 0.2671 | 0.325 | 0.0273 | 343 | 0.0679 | 340 | 0.5850 | 0.0300 | 1.112 |
| AH-19 | H89/2023-9 | Tr. 52 | Period 3B | 1908 | 0.1890 | 0.411 | 0.0015 | 447 | 0.0063 | 162 | 0.3254 | 0.0093 | 1.047 |
| AH-20 | H90/3064-20 | Tr. 58 | Period 3B | 1685 | 0.1154 | 0.401 | 0.0184 | 491 | 0.1503 | 533 | 0.4243 | 0.1292 | 0.061 |
| AH-21 | H88/567-14 | Tr. 50 | Period 3C | 1965 | 0.1989 | 0.331 | 0.0230 | 468 | 0.0809 | 101 | 1.0273 | 0.0054 | 1.253 |
| AH-22 | H88/178-20 | Cemetery area | Period 3C | 2120 | 0.1176 | 0.437 | 0.0330 | 231 | 0.0350 | 384 | 0.3175 | 0.0149 | 3.625 |
| AH-23 | H90/3022-28 | Tr. 58, Mound E | S&D (likely 3B or 3C) | 2289 | 0.3177 | 0.547 | 0.0433 | 354 | 0.1890 | 578 | 0.1430 | 0.0554 | 2.571 |
| AH-24 | H96/7484-1 | Tr. 39, Mound AB | Period 2 | 1888 | 0.2943 | 0.494 | 0.0406 | 401 | 0.0628 | 623 | 0.1530 | 0.1183 | 1.076 |

# APPENDIX 8.6
# INAA DATA FOR AGATE ARTIFACTS FROM MEHRGARH (AMR) AND NAUSHARO (ANS).

Data in parts per million (PPM).

| artifact | Context [number] | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AMR-1 | MR2 Surface | 2520 | 0.0886 | 0.270 | 0.0259 | 80 | 0.0296 | 608 | 0.9750 | 0.0116 | 0.726 |
| AMR-2 | MR2 Surface | 1952 | 0.0658 | 0.269 | 0.0218 | 93 | 0.0217 | 625 | 2.6377 | 0.0367 | 0.851 |
| AMR-3 | MR2 Surface | 2499 | 0.1827 | 0.424 | 0.0193 | 149 | 0.1161 | 511 | 0.8508 | 0.2733 | 1.082 |
| AMR-4 | MR2 Surface | 2048 | 0.0895 | 0.357 | 0.0151 | 67 | 0.0248 | 635 | 0.4956 | 0.0028 | 0.820 |
| AMR-5 | MR2 Surface | 1893 | 0.0636 | 0.192 | 0.0189 | 37 | 0.0356 | 495 | 0.1006 | 0.0089 | 1.507 |
| AMR-6 | MR2 Surface | 2146 | 0.0822 | 0.270 | 0.0184 | 31 | 0.0879 | 439 | 0.9987 | 0.0029 | 0.670 |
| AMR-7 | MR2 Surface | 1727 | 0.0736 | 0.269 | 0.0011 | 57 | 0.0146 | 264 | 0.2232 | 0.1371 | 0.553 |
| AMR-8 | MR2 Surface | 1859 | 0.0877 | 0.424 | 0.0245 | 74 | 0.0416 | 320 | 3.9236 | 0.0853 | 0.528 |
| ANS-1 | Nausharo IC/ID [NS I G8F 88.01.38] | 2227 | 0.1234 | 0.192 | 0.0012 | 208 | 0.0285 | 437 | 0.1786 | 0.3155 | 1.805 |
| ANS-2 | Nausharo III [NS.90.09.06.26] | 1952 | 0.2160 | 0.725 | 0.0218 | 194 | 0.0662 | 541 | 0.2278 | 0.0348 | 1.212 |
| ANS-3 | Nausharo IC [NS G4C (1) 86.18.26] | 2433 | 0.1274 | 0.220 | 0.0228 | 287 | 0.0057 | 659 | 0.3759 | 0.0426 | 1.378 |
| ANS-4 | Nausharo III [NS.89.06.153] | 2024 | 0.0806 | 0.251 | 0.0178 | 193 | 0.0058 | 225 | 0.2820 | 0.0588 | 0.679 |
| ANS-5 | Nausharo IC [NS I 87.4D.53] | 1784 | 0.0839 | 1.250 | 0.0522 | 465 | 9.9652 | 160 | 1.3486 | 0.0360 | 0.695 |
| ANS-6 | Nausharo III [NS.96.06.35.13] | 1789 | 0.0868 | 0.364 | 0.0274 | 156 | 0.0910 | 458 | 1.7987 | 0.0141 | 0.744 |
| ANS-7 | Nausharo III [NS.87.14.92] | 1871 | 0.1400 | 0.315 | 0.0190 | 640 | 0.0799 | 243 | 0.2837 | 0.0319 | 1.328 |

# APPENDIX 8.7

# INAA DATA FOR AGATE ARTIFACTS FROM MOHENJO-DARO (AMD), CHANHU-DARO (ACD) AND NAGWADA (ANGW)

Data in parts per million (PPM)

| artifact | Al | Co | Cr | Eu | Fe | La | Na | Sb | Sc | V |
|---|---|---|---|---|---|---|---|---|---|---|
| AMD-1 | 3234 | 0.3865 | 3.105 | 0.0715 | 1175 | 0.0925 | 1372 | 0.4993 | 0.0279 | 3.177 |
| AMD-2 | 3514 | 0.2594 | 3.032 | 0.0715 | 803 | 0.0480 | 1671 | 1.2017 | 0.0199 | 1.811 |
| AMD-3 | 2579 | 0.3747 | 1.833 | 0.3127 | 539 | 2.1685 | 822 | 0.1345 | 0.0983 | 1.797 |
| AMD-4 | 1850 | 0.1835 | 0.757 | 0.0479 | 200 | 0.0901 | 992 | 0.1407 | 0.0462 | 1.871 |
| AMD-5 | 2456 | 0.2908 | 2.622 | 0.0394 | 672 | 0.0450 | 908 | 0.118 | 0.3899 | 5.594 |
| AMD-6 | 2072 | 0.2022 | 0.938 | 0.065 | 189 | 0.1038 | 1800 | 0.1649 | 0.0738 | 2.348 |
| AMD-7 | 2041 | 0.1605 | 0.579 | 0.0399 | 246 | 0.0873 | 806 | 0.1596 | 0.0756 | 1.749 |
| ACD-1 | 3444 | 0.6120 | 4.386 | 0.1439 | 1876 | 2.4948 | 705 | 0.2566 | 0.0528 | 6.439 |
| ACD-2 | 3046 | 0.4871 | 4.056 | 0.0844 | 1405 | 0.1699 | 2374 | 0.1067 | 0.0705 | 3.596 |
| ACD-3 | 1849 | 0.1639 | 1.223 | 0.0261 | 393 | 0.1031 | 1821 | 0.4212 | 0.0229 | 4.300 |
| ACD-4 | 1642 | 0.1259 | 0.462 | 0.0198 | 541 | 0.0689 | 377 | 0.2913 | 0.0346 | 1.173 |
| ACD-5 | 2710 | 0.2080 | 0.359 | 0.0239 | 320 | 0.0692 | 1162 | 0.6208 | 0.3494 | 2.811 |
| ACD-6 | 3125 | 0.2691 | 0.854 | 0.025 | 714 | 0.0390 | 1165 | 0.2161 | 0.1478 | 20.457 |
| ACD-7 | 2168 | 0.3536 | 1.607 | 0.0662 | 556 | 0.0684 | 1344 | 0.2148 | 0.142 | 8.426 |
| ANGW-1 | 2892 | 0.3448 | 2.727 | 0.0522 | 1029 | 0.1254 | 335 | 0.113 | 0.0332 | 2.431 |
| ANGW-2 | 2290 | 0.2878 | 5.831 | 0.0395 | 753 | 0.6066 | 325 | 0.0977 | 0.103 | 4.382 |
| ANGW-3 | 2313 | 0.4096 | 3.028 | 0.0387 | 890 | 0.1768 | 722 | 0.2556 | 0.6969 | 3.040 |

# APPENDIX 8.8

# FIRST PREDICTED GROUP MEMBERSHIPS (PGMS) FOR AGATE ARTIFACTS GENERATED FROM THREE CDAS IN CHAPTER 8

| Artifact | Figure 8.34 | Figure 8.35 | Figure 8.36 B | Artifact | Figure 8.34 | Figure 8.35 | Figure 8.36 B |
|---|---|---|---|---|---|---|---|
| AH-1 | S-i-S | S-i-S | n/a | ACD-1 | GMB | Gujarat | GMB |
| AH-2 | S-i-S | S-i-S | n/a | ACD-2 | GMB | Gujarat | GMB |
| AH-3 | GMB | Gujarat | GMB | ACD-3 | S-i-S | S-i-S | n/a |
| AH-4 | GMB | Gujarat | GMB | ACD-4 | S-i-S | S-i-S | n/a |
| AH-5 | GMB | Gujarat | GMB | ACD-5 | GMB | Gujarat | GMB |
| AH-6 | GMB | Gujarat | GMB | ACD-6 | GMB | Gujarat | GMB |
| AH-7 | GKK | Gujarat | GKK | ACD-7 | GMB | Gujarat | GMB |
| AH-8 | GKK | Gujarat | GKK | | | | |
| AH-9 | S-i-S | S-i-S | n/a | AMD-1 | GMB | Gujarat | GMB |
| AH-10 | GMB | Gujarat | GMB | AMD-2 | GMB | S-i-S | n/a |
| AH-11 | GMB | Gujarat | GMB | AMD-3 | GMB | Gujarat | GMB |
| AH-12 | GMB | Gujarat | GMB | AMD-4 | GMB | Gujarat | GMB |
| AH-13 | GMB | S-i-S | n/a | AMD-5 | GMB | Gujarat | GMB |
| AH-14 | GRTP | Gujarat | GMB | AMD-6 | GMB | Gujarat | GMB |
| AH-15 | GKK | Gujarat | GKK | AMD-7 | GMB | Gujarat | GMB |
| AH-16 | GMB | Gujarat | GMB | | | | |
| AH-17 | GMB | Gujarat | GMB | AMR-1 | GKK | Gujarat | GKK |
| AH-18 | GKK | Gujarat | GKK | AMR-2 | S-i-S | S-i-S | n/a |
| AH-19 | GKK | Gujarat | GKK | AMR-3 | GKK | Gujarat | GKK |
| AH-20 | S-i-S | S-i-S | n/a | AMR-4 | GKK | Gujarat | GKK |
| AH-21 | GKK | Gujarat | GKK | AMR-5 | GKK | Gujarat | GMB |
| AH-22 | GRTP | Gujarat | GRTP | AMR-6 | GKK | Gujarat | GKK |
| AH-23 | GKK | Gujarat | GKK | AMR-7 | GKK | Gujarat | GKK |
| AH-24 | GMB | Gujarat | GMB | AMR-8 | GRTP | Gujarat | GRTP |
| | | | | | | | |
| ANGW-1 | GRTP | Gujarat | GRTP | ANS-1 | GKK | Gujarat | GKK |
| ANGW-2 | GMB | Gujarat | GMB | ANS-2 | GKK | Gujarat | GMB |
| ANGW-3 | GMB | Gujarat | GMB | ANS-3 | GMB | Gujarat | GMB |
| | | | | ANS-4 | GRTP | Gujarat | GRTP |
| | | | | ANS-5 | S-i-S | S-i-S | n/a |
| | | | | ANS-6 | S-i-S | S-i-S | n/a |
| | | | | ANS-7 | GKK | Gujarat | GKK |

# APPENDIX 8.9

# STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS FOR THE SCATTER AND BOX PLOTS IN CHAPTER 8 GENERATED USING CANONICAL DISCRIMINANT ANALYSIS

| Figures 8.33 & 34 | Function 1 | Function 2 |
|---|---|---|
| Log Al | -.812 | -.511 |
| Log Co | -1.231 | .766 |
| Log Cr | .725 | -.529 |
| Log Eu | .183 | -.586 |
| Log Fe | .679 | -.060 |
| Log La | .018 | .895 |
| Log Na | 1.008 | .406 |
| Log Sb | .009 | .557 |
| Log Sc | .403 | -.578 |
| Log V | -.047 | -.067 |

| Figure 8.35 | Function 1 |
|---|---|
| Log Al | -.682 |
| Log Co | -.318 |
| Log Cr | .025 |
| Log Eu | -.333 |
| Log Fe | .594 |
| Log La | .689 |
| Log Na | .667 |
| Log Sb | .681 |
| Log Sc | -.386 |
| Log V | .077 |

| Figure 8.36 A & B | Function 1 | Function 2 |
|---|---|---|
| Log Al | -.619 | .899 |
| Log Co | -1.280 | -.845 |
| Log Cr | 1.062 | .095 |
| Log Eu | .461 | .317 |
| Log Fe | .246 | .785 |
| Log La | -.512 | -.394 |
| Log Na | 1.052 | -1.207 |
| Log Sb | -.493 | .383 |
| Log Sc | .627 | .053 |
| Log V | -.045 | .142 |

# APPENDIX 9.1

# EMPA OF ARCHAEOLOGICAL AND GEOLOGIC VESUVIANITE-GROSSULAR SAMPLES

Seven vesuvianite-grossular ornament manufacturing debris fragment from Harappa and five geologic samples from two vesuvianite-grossular sources in Pakistan (Muslimbagh ophiolite, Balochistan and Sakhakot-Qila ophiolite, FATA) were examined using electron microprobe analysis (EMPA). Both the energy dispersive spectrometry (EDS) and the wavelength dispersive spectrometry (WDS) capabilities of the probe, as described in Chapter 3, were employed in these analyses.

Phases of vesuvianite and grossular garnet were distinguishable from one another because of their differing Mg contents (< 1% for grossular vs. 2 to 3 % for vesuvianite) as well as the consistently low composition totals (»94-95%) for vesuvianite phases. The low vesuvianite totals are likely due in part to fact that Fluorine (F) was not one of the elements analyzed. Groat and others (1992) found F ranged up to 3.15% of the total in vesuvianites.

## ARCHAEOLOGICAL FRAGMENTS

XRD had previously indicated that four fragments H2000/9999-87, H2000/9999-88, H2000/9999-89 and H2000/9999-93 were composed of solely of vesuvianite. No inclusions or additional phases were identified during in the WDS analyses (Appendix 9.1 Figure 1).

XRD analysis indicated that fragment H2000/9999-90 was primarily composed of vesuvianite and a significant secondary component of grossular garnet. This was confirmed by WDS (Appendix 9.1 Figure 2).

XRD analysis indicated that fragment H98/8499-353 was composed of vesuvianite. Chlorite in fissures within the stone was detected by WDS (Appendix 9.1 Figure 3). No other phases were identified.

XRD analysis indicated that fragment H2000/9999-91 was primarily grossular garnet with traces of chlorite

**Appendix 9.1 Figure 1** WDS compositional data for four vesuviantite fragments from Harappa.

| | H2000/ 9999-87 (n=7) | H2000/9999-88 (n=7) | H2000/9999-89 (n=7) | H2000/9999-93 (n=5) |
|---|---|---|---|---|
| MgO | 2.75 % | 2.99 % | 2.77 % | 2.61 % |
| $Al_2O_3$ | 17.62 % | 18.36 % | 17.73 % | 17.22 % |
| $SiO_2$ | 35.86 % | 36.32 % | 35.89 % | 36.18 % |
| CaO | 36.21 % | 36.33 % | 36.45 % | 35.71 % |
| $TiO_2$ | 0.01 % | 0.00 % | 0.01 % | 0.03 % |
| MnO | 0.03 % | 0.08 % | 0.07 % | 0.05 % |
| FeO | 2.32 % | 0.97 % | 2.08 % | 2.82 % |
| $Na_2O$ | 0.00 % | 0.00 % | 0.00 % | 0.01 % |
| $K_2O$ | 0.01 % | 0.00 % | 0.00 % | 0.01 % |
| $Cr_2O_3$ | 0.01 % | 0.01 % | 0.00 % | 0.07 % |
| Totals | 94.82 % | 95.07 % | 95.01 % | 94.71 % |
| Phase | vesuvianite | vesuvianite | vesuvianite | vesuvianite |

**Appendix 9.1 Figure 2** WDS compositional data for fragment H2000/9999-90

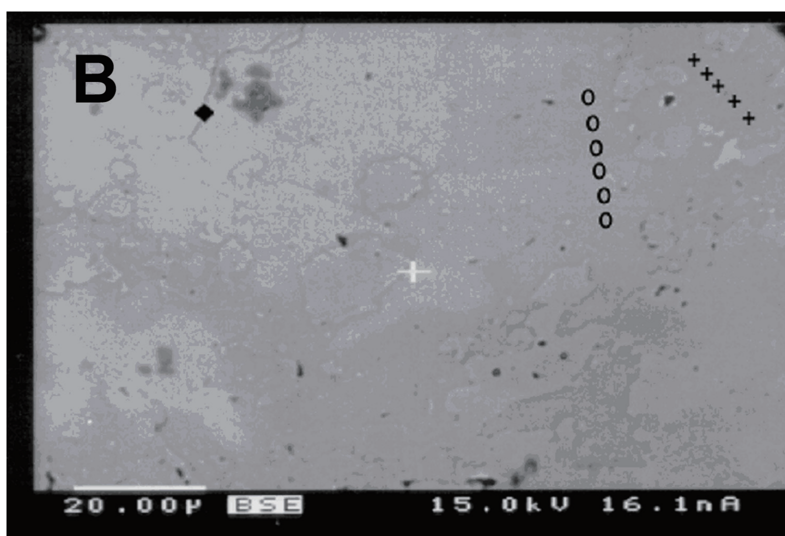
| | **primary phase (average of 7 analyses)** | **secondary phase (average of 3 analyses)** |
|---|---|---|
| **MgO** | 2.75 % | 0.19 % |
| **$Al_2O_3$** | 18.85 % | 21.84 % |
| **$SiO_2$** | 36.16 % | 38.45 % |
| **CaO** | 36.28 % | 37.13 % |
| **$TiO_2$** | 0.02 % | 0.03 % |
| **MnO** | 0.01 % | 0.07 % |
| **FeO** | 0.74 % | 0.95 % |
| **$Na_2O$** | 0.00 % | 0.00 % |
| **$K_2O$** | 0.00 % | 0.00 % |
| **$Cr_2O_3$** | 0.02 % | 0.02 % |
| **Totals** | 94.84 % | 98.69 % |
| **Phase** | **vesuvianite** | **grossular** |

**Appendix 9.1 Figure 3** WDS compositional data for fragment H98/8499-353

| | primary phase (average of 7 analyses) | fissure (1 analysis) |
|---|---|---|
| **MgO** | 2.77 % | 17.73 % |
| **$Al_2O_3$** | 17.56 % | 0.64 % |
| **$SiO_2$** | 35.75 % | 54.78 % |
| **CaO** | 35.98 % | 25.36 % |
| **$TiO_2$** | 0.00 % | 0.01 % |
| **MnO** | 0.03 % | 0.10 % |
| **FeO** | 2.18 % | 1.13 % |
| **$Na_2O$** | 0.00 % | 0.16 % |
| **$K_2O$** | 0.00 % | 0.00 % |
| **$Cr_2O_3$** | 0.02 % | 0.02 % |
| **Totals** | 94.30 % | 99.92 % |
| **Phase** | **vesuvianite** | **chlorite** |

**Appendix 9.1 Figure 4** [**A**] WDS compositional data for fragment H2000/9999-90 [**B**] BSE image of fragment showing the where WDS scans were made on 12 points for three analyses (**0** = phase A, **+** = phase B, ♦ = phase C).

| **A** | **analysis phase A (average of 6 analyses)** | **analysis phase B (average of 5 analyses)** | **fissure (phase C) (n=1)** |
|---|---|---|---|
| **MgO** | 0.01 % | 2.55 % | 18.1 % |
| **$Al_2O_3$** | 22.03 % | 17.83 % | 0.2 % |
| **$SiO_2$** | 38.64 % | 35.46 % | 55.0 % |
| **CaO** | 37.19 % | 36.09 % | 25.4 % |
| **$TiO_2$** | 0.03 % | 0.02 % | 0.0 % |
| **MnO** | 0.08 % | 0.04 % | 0.0 % |
| **FeO** | 1.01 % | 2.13 % | 0.6 % |
| **$Na_2O$** | 0.00 % | 0.01 % | 0.0 % |
| **$K_2O$** | 0.00 % | 0.00 % | 0.0 % |
| **$Cr_2O_3$** | 0.02 % | 0.01 % | 0.0 % |
| **totals** | 99.01 % | 94.14 % | 99.4 % |
| **Phase** | **grossular** | **vesuvianite** | **chlorite** |



**Appendix 9.1 Figure 5** [**A**] WDS compositional data for sample SQ-1. [**B**] BSE image of fragment showing the where WDS scans were made on 11 points for three analyses (**0** = phase A, **+** = phase B, □ = phase C). *Note that the black patches in the image are voids rather than mineral phases.*

| **A** | **analysis phase A (n=3)** | **analysis phase B (n=5)** | **analysis phase C (n=3)** |
|---|---|---|---|
| **MgO** | 0.01 % | 0.00 % | 2.46 % |
| **$Al_2O_3$** | 22.49 % | 22.44 % | 18.30 % |
| **$SiO_2$** | 38.80 % | 38.73 % | 36.13 % |
| **CaO** | 37.04 % | 37.08 % | 36.14 % |
| **$TiO_2$** | 0.02 % | 0.02 % | 0.02 % |
| **MnO** | 0.04 % | 0.06 % | 0.03 % |
| **FeO** | 0.70 % | 0.77 % | 1.92 % |
| **$Na_2O$** | 0.01 % | 0.01 % | 0.03 % |
| **$K_2O$** | 0.01 % | 0.01 % | 0.01 % |
| **$Cr_2O_3$** | 0.01 % | 0.02 % | 0.00 % |
| **totals** | 99.13 % | 99.15 % | 95.04 % |
| **Phase** | **grossular** | **grossular** | **vesuvianite** |

**Appendix 9.1 Figure 6**: WDS compositional data for sample SQ-2

| | **primary phase (average of 7 analyses)** | **black inclusion (n=1)** |
|---|---|---|
| **MgO** | 0.01 % | 7.99 % |
| **$Al_2O_3$** | 22.84 % | 23.79 % |
| **$SiO_2$** | 38.61 % | 0.06 % |
| **CaO** | 37.02 % | 0.17 % |
| **$TiO_2$** | 0.03 % | 0.30 % |
| **MnO** | 0.07 % | 0.00 % |
| **FeO** | 0.20 % | 26.61 % |
| **$Na_2O$** | 0.01 % | 0.01 % |
| **$K_2O$** | 0.01 % | 0.01 % |
| **$Cr_2O_3$** | 0.00 % | 39.11 % |
| **totals** | 98.79 % | 98.06 % |
| **Phase** | **grossular** | **chromite** |

**Appendix 9.1 Figure 7**: WDS compositional data for sample SQ-3

| | **primary phase (average of 7 analyses)** |
|---|---|
| **MgO** | 3.10 % |
| **$Al_2O_3$** | 17.65 % |
| **$SiO_2$** | 35.41 % |
| **CaO** | 36.39 % |
| **$TiO_2$** | 0.03 % |
| **MnO** | 0.07 % |
| **FeO** | 1.75 % |
| **$Na_2O$** | 0.01 % |
| **$K_2O$** | 0.01 % |
| **$Cr_2O_3$** | 0.00 % |
| **totals** | 94.42 % |
| **Phase** | **vesuvianite** |

**Appendix 9.1 Figure 8** WDS compositional data for samples QB-1 and TMJ-1

| | QB-1 (average of 7 analyses) | TMJ-1 (average of 7 analyses) |
|---|---|---|
| MgO | 2.51 % | 2.8 % |
| $Al_2O_3$ | 17.40 % | 15.9 % |
| $SiO_2$ | 36.11 % | 35.7 % |
| CaO | 35.50 % | 35.3 % |
| $TiO_2$ | 0.39 % | 0.3 % |
| MnO | 0.03 % | 0.1 % |
| FeO | 2.52 % | 3.7 % |
| $Na_2O$ | 0.00 % | 0.0 % |
| $K_2O$ | 0.00 % | 0.0 % |
| $Cr_2O_3$ | 0.01 % | 0.0 % |
| totals | 94.47 % | 93.8 % |
| Phase | vesuvianite | vesuvianite |

(variety clinochlore). WDS analyses confirmed the presence of both minerals and also detected a secondary vesuvianite phase (Appendix 9.1 Figure 4 A & B).

## GEOLOGIC SAMPLES

Three samples (SQ-1, SQ-2, SQ-3) from the Sakhakot-Qila Ophiolite (Kot), FATA source formation were probed along with two samples (QB-1, TMJ-1) from the Taleri Mohammed Jan occurence in the Muslimbagh Ophiolite , Balochistan.

SQ-1. Specific gravity = 3.51. XRD analysis indicated that this sample was grossular. This was confirmed by WDS and a minor phase of vesuvianite was also detected (Appendix 9.1 Figure 5 A & B).

SQ-2. Specific gravity = 3.40. XRD analysis indicated that this sample was pure grossular. Small black inclusions are apparent in the stone's translucent milky green matrix. WDS confirmed that grossular was the primary component of this sample and revealed the inclusions to be chromite (Appendix 9.1 Figure 6).

SQ-3. Specific gravity = 3.32. XRD analysis indicated that this sample was vesuvianite. This was confirmed was by WDS (Appendix 9.1 Figure 7). No other phases or inclusions were identified.

QB-1. Specific gravity = 3.33. XRD analysis on a sample of this material indicated that it is composed of vesuvianite and grossular. WDS analysis was only performed on the sample's major phase, which was vesuvianite (Appendix 9.1 Figure 8 *column 1*).

TMJ-1. Specific gravity = 3.26. XRD analysis indicated that the sample was composed of vesuvianite with some chlorite (variety clinochlore). EDS and WDS confirmed this but found no evidence of grossular phases or chromite inclusions (Appendix 9.1 Figure 8 *column 2*).

# APPENDIX 9.2

# ANALYSES OF VESUVIANITE-GROSSULAR FRAGMENTS FROM MOHENJO-DARO

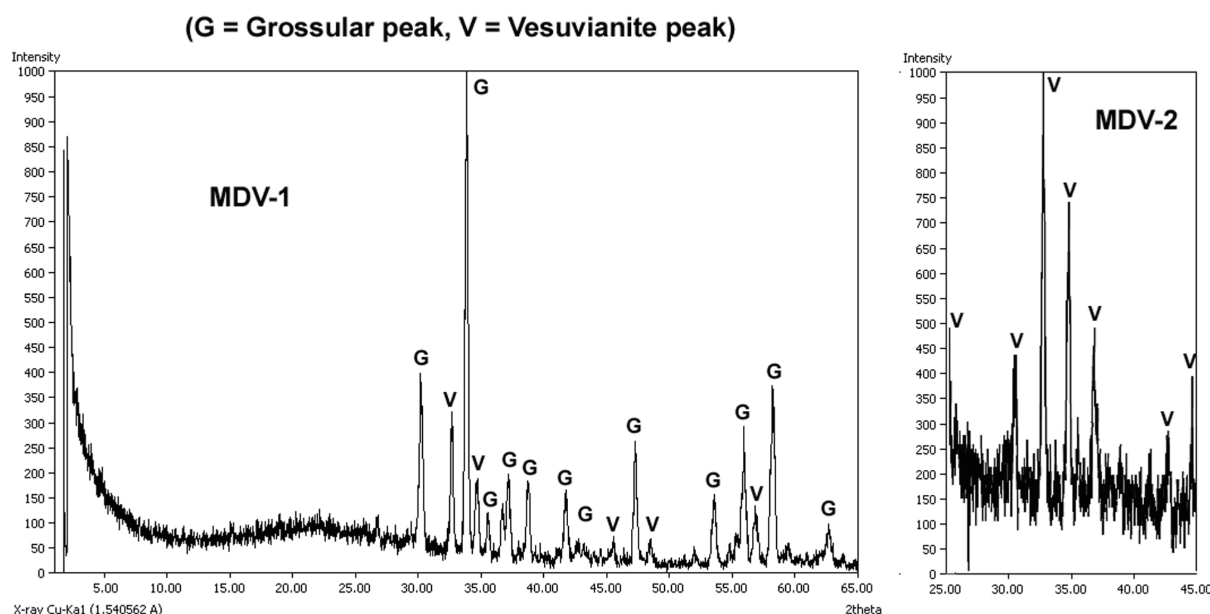
Six vesuvianite-grossular ornament manufacturing debris fragments from Mohenjo-daro were examined using XRD analysis and SG testing (Appendix 9.2 Figure 1).

The XRD scan for sample MDV-1 (Appendix 9.2 Figure 2 left) was conducted at 2-theta 5° to 65°. All others were run only from 2-theta 25° to 45° as this was sufficient to identify and distinguish both vesuvianite and grossular. Only MDV-2 is presented here (Appendix 9.2 Figure 2 right) as the scans for MDV-2 through MDV-6 are basically identical.

Mineralogically, all six of the fragments from Mohenjo-Daro fall within the range of variation exhibited by vesuvianite-grossular artifacts from Harappa.

**Appendix 9.2 Figure 1**: XRD & SG testing results for six greenstone fragments from Mohenjo-Daro

| *Sample* | *Phase(s)* | *Specific gravity* |
|---|---|---|
| MDV 1 | grossular-vesuvianite | 3.41 |
| MDV 2 | vesuvianite | 3.28 |
| MDV 3 | vesuvianite | 3.30 |
| MDV 4 | vesuvianite | 3.28 |
| MDV 5 | vesuvianite | 3.29 |
| MDV 6 | vesuvianite | 3.24 |

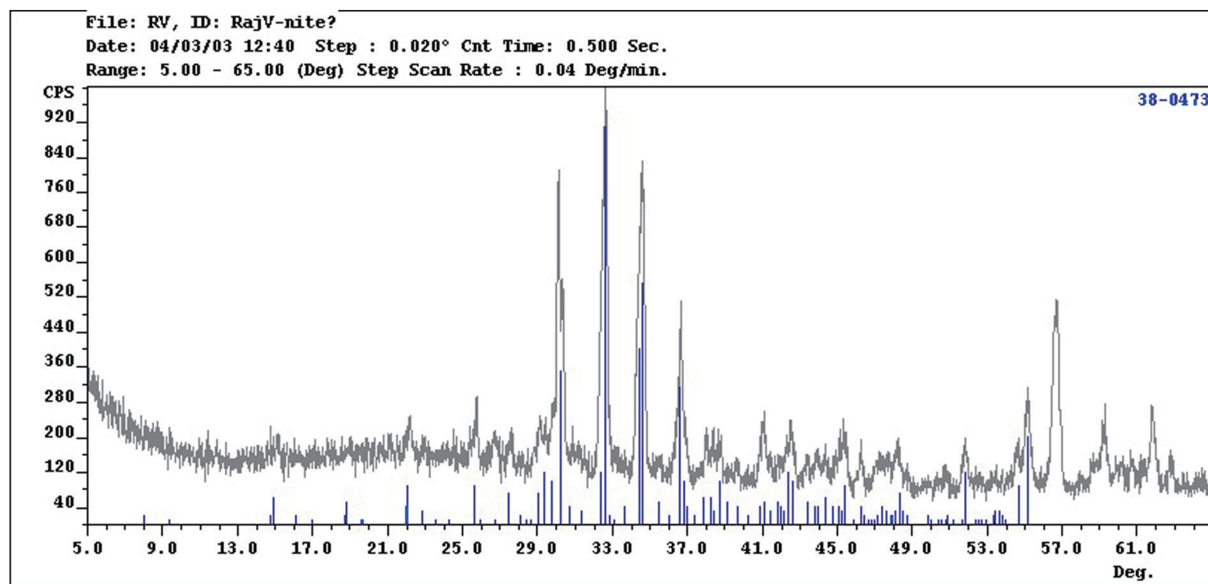



**Appendix 9.2 Figure 2** XRD spectra for two Mohenjo-Daro green stone fragments (MDV-1 and MDV-2).

# APPENDIX 9.3

## XRD OF MASSIVE VESUVIANITE FROM KUMBHALGARH FOREST, RAJASTHAN

The XRD spectrum (Appendix 9.3 Figure 1) for a sample of massive green rock from Kumbalgarh Forest Reserve, Rajasthan confirms that it is composed of vesuvianite. No grossular peaks are present in this particular sample, however.




**Appendix 9.3 Figure 1** Sample of (vertical blue lines indicate vesuvianite peaks).

# APPENDIX 9.4

## INAA DATA FOR VESUVIANITE-GROSSULAR SAMPLES FROM HARAPPA AND MOHENJO-DARO (MDV)

Elemental concentrations in parts per million.

| Artifact | Period | Mound | Trench | Al | Ce | Co | Cr | Eu | Fe | Mn | Na | Sc | Sm | Sr | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H96/7327-2 | 5 | AB | 38 | 110623 | 2.74 | 18.99 | 586 | 0.224 | 20302 | 715 | 79.9 | 74.66 | 0.05 | 650 | 0.507 | 341 |
| H99/9730-11 | 3C | F | 43 | 109543 | 0.89 | 12.63 | 33 | 0.051 | 13280 | 870 | 53.1 | 3.95 | 0.006 | 623 | 0.132 | 36.2 |
| H96/7129-1 | 3C | E | 36 | 92188 | 3.61 | 27.2 | 878 | 0.414 | 20792 | 470 | 109 | 134.5 | 0.06 | 518 | 0.642 | 471 |
| H94/5302-81 | 3C | ET | 22 | 96097 | 1.59 | 24.53 | 269.5 | 0.126 | 19943 | 572 | 103 | 24.6 | 0.009 | 509 | 0.252 | 108 |
| H94/4898-83 | 3C | ET | 27 | 93140 | 0.80 | 10.78 | 3.72 | 0.093 | 18619 | 359 | 73.7 | 0.32 | 0.006 | 432 | 0.094 | 5 |
| H96/6958-41 | 3B | E | 11 | 101568 | 1.93 | 40.74 | 686 | 0.154 | 28103 | 593 | 151 | 32.99 | 0.075 | 536 | 0.308 | 86 |
| H98/8908-8 | 1 | AB | 39 | 108235 | 0.96 | 21.96 | 27 | 0.087 | 22530 | 475 | 144 | 3.19 | 0.005 | 485 | 0.133 | 23.2 |
| MDV-1 | Surface | Moneer Area | n/a | 95973 | 1.28 | 16.56 | 103 | 0.108 | 18567 | 452 | 301 | 18.23 | 0.021 | 443 | 0.194 | 79.6 |
| MDV-2 | Surface | Moneer Area | n/a | 93137 | 1.62 | 17.13 | 163 | 0.141 | 19151 | 418 | 329 | 27.52 | 0.021 | 465 | 0.255 | 115 |
| MDV-3 | Surface | Moneer Area | n/a | 96364 | 0.85 | 13.7 | 13.6 | 0.086 | 18387 | 442 | 72.3 | 2.15 | 0.004 | 466 | 0.109 | 14.2 |

# APPENDIX 9.5

# INAA DATA FOR VESUVIANITE-GROSSULAR SAMPLES FROM SAKHAKOT-QILA (FATA-SQ) AND TALERI MOHAMMED JAN (B-TMJ)

Elemental concentrations in parts per million.

| Sample | Al | Ce | Co | Cr | Eu | Fe | Mn | Na | Sc | Sm | Sr | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FATA-SQ-01 | 136093 | 0.84 | 2.67 | 44.3 | 0.142 | 7595 | 524 | 203 | 1.585 | 0.037 | 556 | 0.119 | 7.8 |
| FATA-SQ-02 | 137086 | 0.72 | 1.44 | 9.64 | 0.137 | 5254 | 440 | 208 | 0.44 | 0.021 | 528 | 0.09 | 6.58 |
| FATA-SQ-03 | 110213 | 0.86 | 11.9 | 6.84 | 0.113 | 15295 | 723 | 87.8 | 2.499 | 0.078 | 582 | 0.128 | 18.3 |
| FATA-SQ-04 | 112945 | 0.95 | 14.4 | 41.2 | 0.11 | 13266 | 470 | 63 | 4.637 | 0.096 | 520 | 0.151 | 27.9 |
| FATA-SQ-05 | 155226 | 0.91 | 4.21 | 209.1 | 0.134 | 5714 | 918 | 76.9 | 2.139 | 0.061 | 689 | 0.121 | 14.4 |
| FATA-SQ-06 | 164444 | 0.85 | 1.6 | 120 | 0.234 | 6087 | 649 | 74.1 | 2.083 | 0.114 | 611 | 0.119 | 11.6 |
| B-TMJ-01 | 94495 | 0.96 | 22.3 | 3.21 | 0.883 | 35350 | 772 | 71.5 | 0.375 | 0.254 | 549 | 0.14 | 18.8 |
| B-TMJ-02 | 87390 | 0.75 | 10.3 | 1.22 | 0.279 | 26161 | 574 | 29.9 | 0.177 | 0.005 | 495 | 0.111 | 17.8 |
| B-TMJ-03 | 87073 | 0.96 | 13.1 | 2.22 | 0.551 | 35870 | 813 | 48.3 | 0.722 | 0.489 | 562 | 0.168 | 28.2 |
| B-TMJ-04 | 89308 | 0.53 | 3.37 | 0.72 | 0.278 | 7814 | 703 | 12.2 | 0.694 | 0.019 | 529 | 0.098 | 61 |
| B-TMJ-05 | 86622 | 0.96 | 13.2 | 3.65 | 0.649 | 36781 | 839 | 53.7 | 1.828 | 0.187 | 571 | 0.184 | 36.8 |
| B-TMJ-06 | 85458 | 0.87 | 12.5 | 3.69 | 0.541 | 34712 | 814 | 47.9 | 0.338 | 0.065 | 567 | 0.208 | 16 |
| B-TMJ-07 | 91995 | 0.92 | 16.9 | 2.79 | 0.767 | 35987 | 733 | 70.8 | 0.402 | 0.238 | 546 | 0.222 | 19.7 |
| B-TMJ-08 | 94171 | 1.22 | 10.1 | 10.4 | 0.379 | 17953 | 283 | 119 | 24.18 | 0.331 | 402 | 0.253 | 11.8 |
| B-TMJ-09 | 95638 | 1.09 | 9.26 | 6.58 | 0.292 | 18015 | 331 | 125 | 18 | 0.227 | 421 | 0.223 | 10.9 |

# APPENDIX 9.6

# INAA DATA FOR VESUVIANITE-GROSSULAR SAMPLES FROM KUMBHALGARH FOREST RESERVE, RAJASTHAN (RAJ-K)

Elemental concentrations in parts per million.

| Sample | Al | Ce | Co | Cr | Eu | Fe | Mn | Na | Sc | Sm | Sr | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RAJ-K-01 | 75650 | 6.77 | 3.89 | 18.3 | 0.509 | 24501 | 313 | 28.8 | 7.266 | 1.072 | 939 | 0.378 | 18.7 |
| RAJ-K-02 | 75342 | 9.25 | 8.82 | 47.7 | 1.169 | 38017 | 315 | 43.3 | 13.2 | 4.327 | 1076 | 0.791 | 15.5 |
| RAJ-K-03 | 73890 | 14.67 | 7.45 | 70.1 | 0.811 | 40296 | 313 | 43.2 | 16.23 | 3.238 | 738 | 0.916 | 23.1 |
| RAJ-K-04 | 73184 | 41.06 | 8.09 | 11.9 | 0.712 | 35635 | 317 | 58.1 | 3.843 | 2.628 | 1132 | 0.737 | 9.81 |
| RAJ-K-05 | 74511 | 8.41 | 12.4 | 33.3 | 0.555 | 41636 | 350 | 41.8 | 4.816 | 1.256 | 931 | 0.44 | 20.1 |
| RAJ-K-06 | 72398 | 8.75 | 10 | 18.7 | 0.61 | 40853 | 351 | 47.6 | 4.763 | 1.291 | 761 | 0.494 | 19.3 |
| RAJ-K-07 | 80427 | 116.3 | 8.48 | 59.9 | 1.253 | 42754 | 338 | 55 | 18.2 | 7.021 | 1446 | 2.485 | 18 |

# APPENDIX 9.7

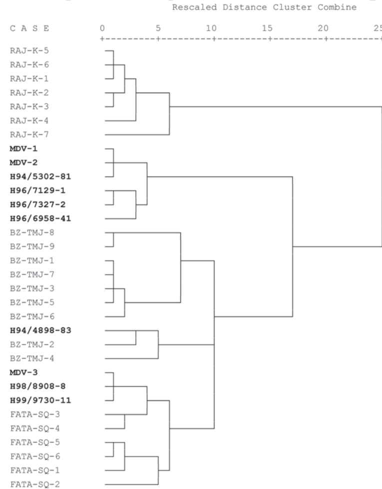
## STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS FOR FIGURE 9.8

| Element | Function 1 | Function 2 |
|---|---|---|
| Log Al | 2.164 | -.723 |
| Log Ce | .066 | .855 |
| Log Co | .357 | -1.367 |
| Log Cr | -1.227 | 1.814 |
| Log Eu | -1.243 | -1.776 |
| Log Fe | .304 | .598 |
| Log La | -2.079 | -1.297 |
| Log Mn | .811 | -.985 |
| Log Na | 1.843 | 1.386 |
| Log Sc | -.341 | -2.036 |
| Log Sm | 1.420 | 2.271 |
| Log U | -.163 | 1.238 |
| Log V | .818 | -.922 |

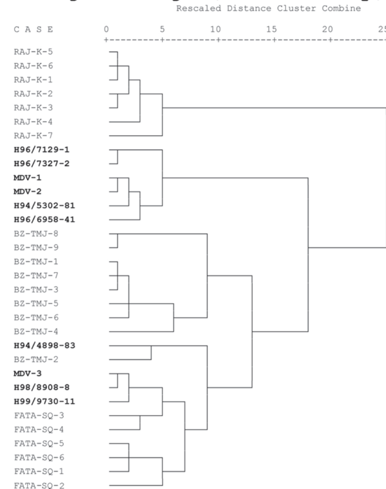
# APPENDIX 9.8

## SIX ALTERNATE CLUSTERING STRATEGIES USING THE VESUVIANITE-GROSSULAR COMPARATIVE DATA

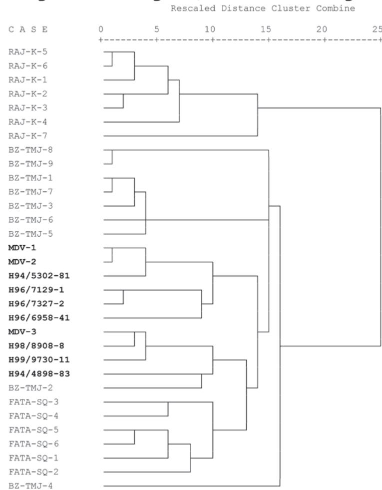
### Average Linkage (Between Groups)



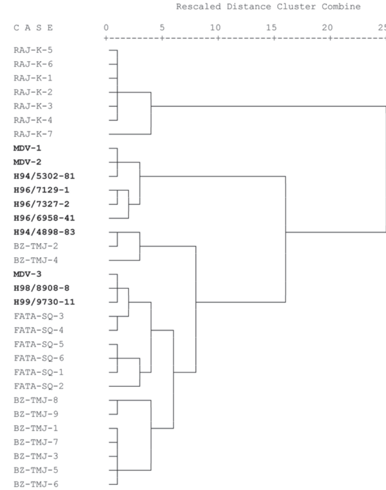

### Average Linkage (Within Group)



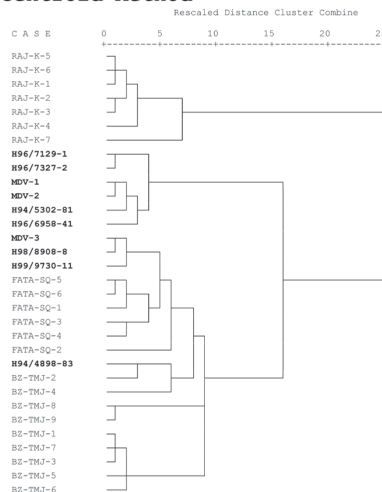

### Single Linkage (Nearest Neighbor)



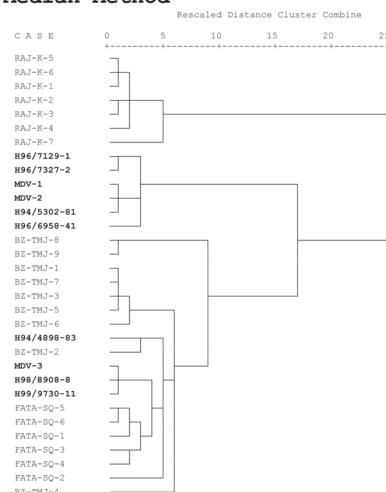

### Complete Linkage (Furthest Neighbor)




### Centroid Method




### Median Method



# APPENDIX 9.9

## IS THE VESUVIANITE-GROSSULAR / "ERNESTITE" ASSOCIATION GENUINE?

In Chapter 9, I showed that the spatial and temporal distribution patterns of "Ernestite" and vesuvianite-grossular artifacts at Harappa are practically mirror images of one another. With the exception of a single and possibly anomalous vesuvianite-grossular flake in Period 1 levels, each variety of stone begins to appear in the site's archaeological record around periods 3B and 3C. Both are varieties are found mainly on mounds E and ET. Moreover, when association at the level of shared stratigraphically secure excavation lot is considered, we see that in roughly one out of every three lots (32.4%) in which an "Ernestite" artifact was recovered a vesuvianite-grossular artifact was also present. I argue that it is no coincidence that each material appears at exactly the same time *when* (ca. periods 3B and 3C) and, largely, in the same places *where* (Mound E/ET) beadmakers were using the other one. Simply put, the reason is that vesuvianite-grossular beads could not have been drilled without use of "Ernestite" bits. Whether or not the discovery of "Ernestite" and its unique drilling properties (discussed in Appendix 4.5) finally allowed beadmakers to use vesuvianite-grossular or if desire to use vesuvianite-grossular necessitated the development of "Ernestite" is a "chicken and egg" type question. Who knows? They both appear at the same time and place.

However, is this association indeed *genuine*? That is, does the evident spatial and temporal pattern stem from the actual behaviors of Harappans? Or, could it be a product of something else? As I discussed in detail in Chapter 4, Harappa's rock and mineral assemblage is unevenly distributed through time and space. Some of this is due to the physical constraints of the site (Harappa's deeply buried early occupation levels) while some is due to the research strategies of the HARP excavators (an early and sustained focus on mounds E and ET). Although I think that in Chapter 9 I satisfactorily demonstrated the vesuvianite-grossular / "Ernestite" association to be valid despite the possibility of recovery bias, here I present some additional, supplementary observations regarding this issue.

First recall Figure 4.10, which in its second column shows how all of Harappa's rock and mineral artifacts from secure contexts (n = 32,365) are distributed through each chronological phase. The distributional bias toward Period 3C at the expense of earlier levels is clear. Now look at Figure 4.12, which shows the spatial and temporal presence or absence of all rock and mineral varieties at Harappa in order of decreasing abundance in the assemblage. The rock and mineral sub-assemblages from the early levels are clearly not as diverse as Period 3C. Part of the reason for this, I have argued, is because the less abundant overall varieties (those at the bottom of the table) were not as apt to be recovered in the early levels. However, "Ernestite" and, in particular, vesuvianite-grossular have fairly sizeable sub-assemblages. If those stones were used to any significant degree (or if at all) prior to Period 3B then I would expect at least a few examples to have been recovered from Early Harappan and Period 3A levels. For Appendix 9.9 Figure 1 (next page), I used the overall rock and mineral assemblage temporal distribution percentages from the second column of Figure 4.10 as a formula for making (admittedly) crude predictions of the number of artifacts that might be expected in each phase for those material varieties and a select number of others. If vesuvianite-grossular was used and discarded throughout the entire sequence at Harappa, then perhaps 45 or so examples out of the 180

**Appendix 9.9 Figure 1** The predicted temporal distribution of select rock and mineral varieties in secure contexts based on overall assemblage distribution versus the actual temporal distribution of those varieties

| Period | *rock & mineral assemblage Distribution (n = 32,365)* | predicted **vesuvianite** distribution (n=180) | actual **vesuvianite** distribution (n=180) | predicted **“Ernestite”** distribution (n=40) | actual **“Ernestite”** distribution (n=40) |
|---|---|---|---|---|---|
| **1** | 11.59% | 21 | 1 | 4.6 | 0 |
| **2** | 7.95% | 14 | 0 | 3.2 | 0 |
| **3A** | 6.10% | 11 | 0 | 2.4 | 0 |
| **3B** | 10.88% | 20 | 4 | 4.4 | 2 |
| **3C** | 62.81% | 113 | 174 | 25.1 | 38 |
| **4/5** | 0.67% | 1 | 1 | 0.3 | 0 |
| | | | | | |
| **Period** | *rock & mineral assemblage Distribution (n = 32,365)* | predicted **igneous** distribution (n=252) | actual **igneous** distribution (n=252) | predicted **alabaster** distribution (n=212) | actual **alabaster** distribution (n=212) |
| **1** | 11.59% | 29.2 | 3 | 24.6 | 3 |
| **2** | 7.95% | 20.0 | 13 | 16.9 | 3 |
| **3A** | 6.10% | 15.4 | 7 | 12.9 | 9 |
| **3B** | 10.88% | 27.4 | 34 | 23.1 | 18 |
| **3C** | 62.81% | 158.3 | 192 | 133.2 | 179 |
| **4/5** | 0.67% | 1.7 | 3 | 1.4 | 0 |
| | | | | | |
| **Period** | *rock & mineral assemblage Distribution (n = 32,365)* | predicted **lapis lazuli** distribution (n=75) | actual **lapis lazuli** distribution (n=75) | predicted **amazonite** distribution (n=12) | actual **amazonite** distribution (n=12) |
| **1** | 11.59% | 8.7 | 4 | 1.7 | 3 |
| **2** | 7.95% | 6.0 | 11 | 1.2 | 2 |
| **3A** | 6.10% | 4.6 | 2 | 0.9 | 0 |
| **3B** | 10.88% | 8.2 | 24 | 1.6 | 2 |
| **3C** | 62.81% | 47.1 | 32 | 9.4 | 5 |
| **4/5** | 0.67% | 0.5 | 2 | 0.1 | 3 |

artifacts in that material sub-assemblage from secure-contexts might be expected to have been recovered from levels prior to Period 3B. However, with the exception of the single and possibly anomalous flake from Period 1 (this instance detailed in Chapter 9), none were. Likewise, no “Ernestite” artifacts whatsoever were recovered from the early periods in question, although perhaps around ten examples might have been expected. For the purpose of comparison, I have applied the same formula to other rock and mineral varieties having sub-assemblages of comparable sizes – igneous rock and alabaster for vesuvianite-grossular and lapis lazuli and amazonite for “Ernestite.” Although the predicted versus the actual distributions for those materials did not always correspond to one another (indicating that overall assemblage distribution is not a good predictor of the distribution of any one material type), it was almost always the case that some examples of those materials were recovered from pre-Period 3B chronological phases. This suggests to me that the absence (or near absence) of vesuvianite-grossular and “Ernestite” from

**Appendix 9.9 Figure 2** The predicted spatial distribution of select rock and mineral varieties across the mounds at Harappa based on overall assemblage distribution versus the actual spatial distribution of those varieties.

| Mound | *rock & mineral assemblage Distribution (n=56,350)* | predicted **vesuvianite** distribution (n=534) | actual **vesuvianite** distribution (n=543) | predicted **"Ernestite"** distribution (n=75) | actual **"Ernestite"** distribution (n=75) |
|---|---|---|---|---|---|
| **AB** | 19.54% | 106.1 | 5 | 14.7 | 4 |
| **E** | 40.14% | 218.0 | 300 | 30.1 | 30 |
| **ET** | 26.51% | 143.9 | 190 | 19.9 | 37 |
| **F** | 6.73% | 36.5 | 5 | 5.0 | 1 |
| **Off** | 7.08% | 38.4 | 43 | 5.3 | 3 |

| Mound | *rock & mineral assemblage Distribution (n=56,350)* | predicted **igneous** distribution (n=455) | actual **igneous** distribution (n=455) | predicted **alabaster** distribution (n=422) | actual **alabaster** distribution (n=422) |
|---|---|---|---|---|---|
| **AB** | 19.54% | 88.9 | 95 | 82.5 | 154 |
| **E** | 40.14% | 182.6 | 158 | 169.4 | 61 |
| **ET** | 26.51% | 120.6 | 76 | 111.9 | 124 |
| **F** | 6.73% | 30.6 | 97 | 28.4 | 55 |
| **Off** | 7.08% | 32.2 | 29 | 29.9 | 28 |

| Mound | *rock & mineral assemblage Distribution (n=56,350)* | predicted **lapis lazuli** distribution (n=174) | actual **lapis lazuli** distribution (n=174) | predicted **amazonite** distribution (n=21) | actual **amazonite** distribution (n=21) |
|---|---|---|---|---|---|
| **AB** | 19.54% | 34.0 | 74 | 3.9 | 13 |
| **E** | 40.14% | 69.8 | 48 | 8.0 | 0 |
| **ET** | 26.51% | 46.1 | 15 | 5.3 | 4 |
| **F** | 6.73% | 11.7 | 12 | 1.3 | 3 |
| **Off** | 7.08% | 12.3 | 25 | 1.4 | 1 |

early levels at Harappa is probably not due to recovery bias alone. These rock varieties were simply not used at during those phases.

Next we turn to my contention that Harappans living and working on mounds E and ET were the primary users of vesuvianite-grossular and "Ernestite." Figure 4.9 from Chapter 4 indicates that 66% of the rock and mineral assemblage at Harappa was recovered from excavation or survey on the combined area of those two mounds (Mound E/ET). This shows that there is unquestionably a recovery bias toward the area of the site where vesuvianite-grossular and "Ernestite" artifacts are most heavily concentrated. However, is it enough to account for the fact that around 90% of both rock varieties were recovered from those mounds? For Appendix 9.9 Figure 2 (next page), I have used the used the assemblage spatial distribution percentages for the entire assemblage of rock and mineral artifacts (Figure 4.9) to make crude predictions about how vesuvianite-grossular, "Ernestite," and the selected sub-assemblages of comparable size was be distributed if they were being used more or less to the same degree in all parts of the site. Although once again the predicted distributions and the actually distributions for the comparable sub-assemblages do not always

match perfectly, none of them are as sharply biased toward mounds E-ET as vesuvianite-grossular and "Ernestite" clearly area. This leads me to conclude that the spatial patterning of the latter two materials is, at least partially, a genuine product of behaviors of ancient residents of Harappa.

# APPENDIX 10.1

# SULFUR AND STRONTIUM ISOTOPE VALUES FOR ALABASTER ARTIFACTS FROM HARAPPA, MOHENJO-DARO, REHMAN DHERI AND MUSA KHEL

| Site | Artifact | Sample number | Period | Mound-Trench | $\delta^{34}S$ ‰ | Sr 87/86 |
|---|---|---|---|---|---|---|
| Harappa | fragment | H2000/9572-22 | 2 | AB - 39 | 34.769 | 0.710059 |
| Harappa | fragment | H98/8486-84 | 2 | AB - 39 | 28.664 | 0.711125 |
| Harappa | bangle | H2000/2126-9 | 3A | E - 54 | 14.245 | 0.711609 |
| Harappa | fragment | H95/4686-7 | 3B | ET - 10 | 26.488 | 0.714056 |
| Harappa | fragment | H94/4469-406 | 3B | ET - 10 | 23.402 | 0.712165 |
| Harappa | fragment | H95/7018-11 | 3C | AB - 31 | 25.756 | 0.712064 |
| Harappa | fragment | H98/8308-170 | 3C | AB - 39 | 36.223 | 0.708499 |
| Harappa | fragment | H98/8310-64 | 3C | AB - 39 | 20.128 | 0.709541 |
| Harappa | fragment | H98/8327-16 | 3C | AB - 39 | 23.602 | 0.708272 |
| Harappa | ringstone | H98/7715-9 | 3C | AB - 42 | 21.971 | 0.709034 |
| Harappa | fragment | H2001/11502-3 | 3C | E - 11 | 27.465 | 0.710068 |
| Harappa | vessel | H99/8890-93 | 3C | E - 11 | 21.293 | 0.712989 |
| Harappa | bangle | H2000/2207-20 | 3C | E - 54 | 21.116 | 0.710131 |
| Harappa | plug | H2000/2733-16 | 3C | E - 55 | 18.674 | 0.713016 |
| Harappa | fragment | H94/3987-32 | 3C | E - 7/8 | 14.933 | 0.708542 |
| Harappa | fragment | H95/4731-2 | 3C | ET - 19 | 20.039 | 0.709318 |
| Harappa | fragment | H95/4921-12 | 3C | ET - 28 | 21.260 | 0.711188 |
| Harappa | fragment | H95/4954-19 | 3C | ET - 28 | 23.624 | 0.708876 |
| Harappa | fragment | H95/5729-151 | 3C | ET -32 | 19.640 | 0.711863 |
| Harappa | fragment | H2000/10046-5 | 3C | F - 43 | 21.460 | n/a |
| Harappa | fragment | H98/8631-2 | 3C | F - 43 | 23.358 | 0.707956 |
| Harappa | fragment | H99/9765-2 | 3C | F - 43 | 21.615 | 0.708487 |
| Harappa | fragment | H99/8387-107 | surface | AB - 39 | 23.624 | 0.713547 |
| Harappa | vessel | H2000/2102-907 | surface | E - 54 | 21.249 | n/a |
| Harappa | bangle | H2000/2139-128 | surface | E - 54 | 20.505 | 0.712308 |
| Harappa | fragment | H96/7218-10 | surface | F - 37 | 22.881 | 0.708216 |
| Harappa | pendent | H94/4999-511 | unknown | unknown | 19.784 | 0.709347 |
| Harappa | ball | Vats 3558 | unknown | AB? | 19.107 | n/a |
| Harappa | weight | Vats 13799 | unknown | AB? | 22.459 | 0.708033 |
| Mohenjo-daro | vessel | MD-1 | surface | DK area | 16.820 | 0.708719 |
| Musa Khel | fragment | MK-1 | surface | n/a | 31.128 | 0.708490 |
| Musa Khel | fragment | MK-2 | surface | n/a | 26.832 | 0.712666 |
| Rehman Dheri | fragment | RD-1 | surface | n/a | 25.500 | 0.709975 |

# APPENDIX 10.2

## SULFUR AND STRONTIUM ISOTOPE VALUES FOR GEOLOGIC SAMPLES OF ALABASTER FROM SOURCES IN THE SULAIMAN MOUNTAINS, SALT RANGE AND KOHAT

| Sample | Region (Province) | Source/Location | Age | $\delta^{34}S$ ‰ | Sr 87/86 |
|---|---|---|---|---|---|
| BG19 | Sulaimans (Balochistan) | Bala Dhaka - Karher | Eocene | 22.337 | 0.707846 |
| BG-20 | Sulaimans (Balochistan) | Bala Dhaka - Karher | Eocene | 22.193 | 0.707778 |
| BG21 | Sulaimans (Balochistan) | Barkhan | Eocene | 22.725 | 0.707793 |
| BG-13 | Sulaimans (Balochistan) | Chamlang Mari | Eocene | 22.559 | 0.707784 |
| BG-14 | Sulaimans (Balochistan) | Chamlang Mari | Eocene | 22.592 | 0.707805 |
| BG-04 | Sulaimans (Balochistan) | Dera Bugti | Eocene | 23.414 | 0.707750 |
| BG-05 | Sulaimans (Balochistan) | Dera Bugti | Eocene | 23.458 | 0.707817 |
| BG-03 | Sulaimans (Punjab) | DG Khan - Zinda Pir | Eocene | 24.102 | 0.707766 |
| DGK-2 | Sulaimans (Punjab) | DG Khan - Zinda Pir | Eocene | 23.769 | n/a |
| BG-08 | Sulaimans (NWFP) | DI Khan - Drazinda | Eocene | 22.415 | 0.707825 |
| BG-09 | Sulaimans (NWFP) | DI Khan - Drazinda | Eocene | 20.594 | 0.707835 |
| DIK-3 | Sulaimans (NWFP) | DI Khan - Drazinda | Eocene | 23.025 | n/a |
| DIK-4 | Sulaimans (NWFP) | DI Khan - Drazinda | Eocene | 22.847 | n/a |
| BG17 | Sulaimans (Balochistan) | Kore More | Eocene | 23.402 | 0.707825 |
| BG18 | Sulaimans (Balochistan) | Kore More | Eocene | 23.669 | 0.707824 |
| BG-22 | Sulaimans (Balochistan) | Kurcha-Rakni | Eocene | 22.792 | 0.707745 |
| BG-06 | Sulaimans (Balochistan) | Lakha Kach-Rakni | Eocene | 22.903 | 0.707824 |
| BG-07 | Sulaimans (Balochistan) | Lakha Kach-Rakni | Eocene | 23.214 | 0.707805 |
| BG-10 | Sulaimans (Balochistan) | Nisau-Vitakri | Eocene | 23.769 | 0.707779 |
| BG-11 | Sulaimans (Balochistan) | Nisau-Vitakri | Eocene | 23.647 | 0.707804 |
| BG-15 | Sulaimans (Balochistan) | Nodo | Eocene | 23.824 | 0.707785 |
| BG-16 | Sulaimans (Balochistan) | Nodo | Eocene | 24.202 | 0.707795 |
| BG-01 | Sulaimans (Balochistan) | Spintangi | Eocene | 24.890 | 0.707704 |
| BG-02 | Sulaimans (Balochistan) | Spintangi | Eocene | 24.612 | 0.707748 |
| KJ-1 | Kohat (NWFP) | Jatta | Eocene | 19.173 | 0.707906 |
| KJ-2 | Kohat (NWFP) | Jatta | Eocene | 19.029 | 0.708949 |
| KBK-1 | Kohat (NWFP) | Bahad-ur-Khel | Eocene | 19.118 | 0.707747 |
| KBK-2 | Kohat (NWFP) | Bahad-ur-Khel | Eocene | 20.084 | n/a |

| Sample | Region (Province) | Source/Location | Age | $\delta^{34}S$ ‰ | Sr 87/86 |
|---|---|---|---|---|---|
| SRL-1 | Salt Range (Punjab) | 6km north of Lille | Infra-Cambrian | 37.699 | 0.709053 |
| SRL-2 | Salt Range (Punjab) | 6km north of Lille | Infra-Cambrian | 37.400 | 0.709021 |
| BK-1 | Salt Range (Punjab) | Buri Khel | Infra-Cambrian | 36.745 | 0.708139 |
| BK-2 | Salt Range (Punjab) | Buri Khel | Infra-Cambrian | 36.722 | 0.708048 |
| BK-3 | Salt Range (Punjab) | Buri Khel | Infra-Cambrian | 36.878 | 0.708152 |
| SRDK-1 | Salt Range (Punjab) | Daud Khel | Eocene | 25.278 | 0.711878 |
| SRDK-2 | Salt Range (Punjab) | Daud Khel | Eocene | 25.467 | 0.711899 |
| SRDK-3 | Salt Range (Punjab) | Daud Khel | Eocene | 25.334 | n/a |
| JSR-1 | Salt Range (Punjab) | Jalalpur | Infra-Cambrian | 31.539 | 0.710204 |
| JSR-2 | Salt Range (Punjab) | Jalalpur | Infra-Cambrian | 34.036 | 0.708770 |
| JSR-3 | Salt Range (Punjab) | Jalalpur | Infra-Cambrian | 34.480 | n/a |
| KDSR-1 | Salt Range (Punjab) | Katha Dome | Infra-Cambrian | 30.151 | 0.708570 |
| KDSR-2 | Salt Range (Punjab) | Katha Dome | Infra-Cambrian | 30.751 | 0.708543 |
| KDSR-3 | Salt Range (Punjab) | Katha Dome | Infra-Cambrian | 30.762 | n/a |
| SRK-2 | Salt Range (Punjab) | Khewra | Infra-Cambrian | 35.957 | 0.708059 |
| SWN-1 | Salt Range (NWFP) | Saiduwali Nala | Eocene | 26.488 | 0.711462 |
| SWN-2 | Salt Range (NWFP) | Saiduwali Nala | Eocene | 26.444 | 0.710686 |
| SWN-3 | Salt Range (NWFP) | Saiduwali Nala | Eocene | 26.621 | 0.711447 |

# APPENDIX 10.3

## LIST OF PINK BI-PYRAMIDAL QUARTZ CRYSTALS (MARI "DIAMONDS") FROM HARAPPA

| artifact (year-lot-record) | mound / area | trench / context | period |
|---|---|---|---|
| H86/0.031-20 | E - western slope | surface | unknown |
| H86/17-8 | Cemetery | Harappan dump | 3C |
| H89/2024-16 | E | 52 | 3B |
| H89/2025-5 | E | 52 | 3B |
| H93/3516-34 | E | 4 | 3 or later |
| H94/4814-53 | ET | 19 | 3 or later |
| H95/5166-55 | E | 7_8 | 3C |
| H96/6219-36 | ET | 35 | 3C |
| H96/7401-60 | AB | 39 | 2/3 mix |
| H96/7467-613 | AB | 39 | 2/3 mix |

# APPENDIX 11.1

# ARCHAEOLOGICAL LIMESTONE SAMPLES FROM HARAPPA ANALYZED FOR THIS STUDY

UPPERCASE text indicates analysis variety.

| sample # | artifact # | artifact type | texture | color |
|---|---|---|---|---|
| HLS-001 | H89/1063-28 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4 |
| HLS-002 | H2000/9999-72 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4 |
| HLS-003 | H2000/2091-35 | fragment | MICRITIC | Very pale orange 10YR 8/2 rapidly blending to Grayish red 5Y 4/2 |
| HLS-004 | H2000/2500-3 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4 |
| HLS-005 | H2000/2085-7 | ringstone fragment | sandy | Dark GOLDEN orange 10YR 6/6 to Pale reddish brown 10R 5/4 |
| HLS-006 | H95/7008-12 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4 |
| HLS-007 | Vats (no #) | ringstone | sandy | BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2 |
| HLS-008 | Vats (no #) | ringstone | sandy | BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2 |
| HLS-009 | H95/7110-4 | fragment | MICRITIC | Grayish orange 10YR 7/4 with some black spots |
| HLS-010 | H2001/9613-7 | shaped stone | MICRITIC | Pale yellowish brown 10YR 6/2 mottled Grayish orange 10YR 7/4 |
| HLS-011 | H86/0.025-123 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-012 | H93/3862-9 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2 |
| HLS-013 | H93/3892-15 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-014 | H93/3892-56 | ringstone fragment | sandy | Dark GOLDEN orange 10YR 6/6 to Pale reddish brown 10R 5/4 |
| HLS-015 | H94/667-1 | ringstone fragment | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-016 | H94/3937-1 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-017 | H95/4940-106 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-018 | H95/5170-57 | fragment | sandy | Grayish red 10R 4/2 (BANDED group) |
| HLS-019 | H95/5170-58 | fragment | sandy | Grayish red 10R 4/2 to Moderate yellowish brown 10YR 5/4 (BANDED group) |
| HLS-020 | H95/5195-12 | ringstone fragment | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-021 | H95/7017-3 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-022 | H96/7150-5 | fragment | sandy | Dark yellowish orange 10YR 6/6 to Moderate reddish brown 10R 4/6 (BANDED group) |
| HLS-023 | H96/7218-5 | fragment | sandy | Dark yellowish orange 10YR 6/6 to Moderate reddish brown 10R 4/6 (BANDED group) |
| HLS-024 | H98/8306-20 | ringstone fragment | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-025 | H98/8334-261 | fragment | sandy | Dark GOLDEN orange 10YR 6/6 to Moderate reddish brown 10R 4/6 |
| HLS-026 | H98/8324-19 | fragment | sandy | Dark GOLDEN orange 10YR 6/6 to Grayish orange 10YR 7/4 |
| HLS-027 | H98/8324-14 | fragment | sandy | Dark GOLDEN orange 10YR 6/6 to Grayish orange 10YR 7/4 |
| HLS-028 | H98/8310-147 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-029 | H98/8308-138 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2 |

| sample # | artifact # | artifact type | texture | color |
|---|---|---|---|---|
| HLS-030 | H98/8313-116 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-031 | H98/8323-49 | fragment | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-032 | H98/8335-37 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-033 | H98/8331-68 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-034 | H98/8321-2 | ringstone fragment | sandy | Dark GOLDEN orange 10YR 6/6 to Moderate reddish brown 10R 4/6 |
| HLS-035 | H98/8306-257 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-036 | H98/8303-36 | fragment | sandy | Moderate yellowish brown 10YR 5/4 (BANDED group) |
| HLS-037 | H99/9724-50 | fragment | sandy | Moderate yellowish brown 10YR 5/4 to Dark yellowish brown 10YR 4/2 |
| HLS-038 | H99/9722-16 | fragment | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-039 | H2000/2091-36 | fragment | sandy | Dark yellowish orange 10YR 6/6 (BANDED group) |
| HLS-040 | H2000/2520-3 | fragment | sandy | BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2 |
| HLS-041 | Vats (T#148) | shaped stone | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-042 | Vats (T#149) | shaped stone | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-043 | Vats (T#150) | shaped stone | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-044 | Vats # 4534 | shaped stone | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-045 | Vats (T#152) | shaped stone | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-046 | HM#10548 | shaped stone | sandy | Dark GOLDEN orange 10YR 6/6 |
| HLS-047 | HM#88798 | door pivot? | fine sandy | Grayish Orange 10YR 7/4 (BANDED group) |
| HLS-048 | H96/7401-2 | fragment | fine sandy | Moderate reddish brown 10R 3/4 (GOLDEN group) |
| HLS-049 | H96/7307-1 | ringstone fragment | fine sandy | Moderate reddish brown 10R 3/4 (GOLDEN group) |
| HLS-050 | H98/8334-4 | fragment | fine sandy | Pale reddish brown 10R 5/4 (GOLDEN group) |
| HLS-051 | H98/8334-3 | fragment | fine sandy | Pale reddish brown 10R 5/4 (GOLDEN group) |
| HLS-052 | H2000/2088-101 | fragment | MICRITIC | Pale brown 5YR 5/2 to Grayish red 5R 4/2 |
| HLS-053 | H2000/2109-19 | fragment | MICRITIC | Grayish orange 10YR 7/4 |
| HLS-054 | H95/4962-27 | fragment | MICRITIC | Grayish orange 10YR 7/4 with some black spots |
| HLS-055 | H93/3892-82 | drain cover? | MICRITIC | Pale yellowish brown 10 YR 6/2 to Grayish orange 10YR 7/4 |
| HLS-056 | H93/4051-12 | fragment | sandy | Grayish Orange 10YR 7/4 (BANDED group) |
| HLS-057 | H96/6251 | fragment | MICRITIC | Grayish Orange 10YR 7/4 to Very pale orange 10YR 8/2 |
| HLS-058 | H94/3990-19 | fragment | MICRITIC | Grayish Orange 10YR 7/4 |
| HLS-060 | H95/4719-1 | fragment | MICRITIC | Dark yellowish orange 10YR 6/6 to Grayish Orange 10YR 7/4 |
| HLS-061 | H99/8394-20 | fragment | MICRITIC | Grayish Orange 10YR 7/4 |
| HLS-062 | Vats (6098) | shaped stone | sandy | Very dusky purple 5RP 2/2 to GRAYish red purple 5RP 4/2 |
| HLS-063 | Vats (T#146) | shaped stone | sandy | Very dusky purple 5RP 2/2 to GRAYish red purple 5RP 4/2 |
| HLS-064 | Vats (T#141) | shaped stone | fine sandy | Brownish GRAY 5YR 4/1 |
| HLS-065 | T#130 (B-7) | shaped stone | sandy crystalline | GRAYish purple 5P 4/2 to Grayish red purple 5RP 4/2 |
| HLS-066 | H2001/11810-4 | ringstone broken | sandy crystalline | GRAYish purple 5P 4/2 to Grayish red purple 5RP 4/2 |
| HLS-067 | Vats (T#140) | shaped stone | sandy crystalline | GRAYish purple 5P 4/2 to Grayish red purple 5RP 4/2 |

| sample # | artifact # | artifact type | texture | color |
|---|---|---|---|---|
| HLS-068 | H98/8313-117 | fragment | MICRITIC | Dark reddish brown 10R 3/4 |
| HLS-069 | H98/8306-126 | ringstone fragment | fine sandy | Dark yellowish orange 10YR 6/6 (GOLDEN group) |
| HLS-071 | H99/8759-3 | fragment | chalky | WHITE N9 |
| HLS-072 | H98/8603-41 | fragment | chalky | WHITE N9 |
| HLS-073 | H2003-9904-16 | fragment | chalky | WHITE N9 |
| HLS-075 | H2000/2748-13 | fragment | chalky | WHITE N9 |
| HLS-076 | H2000/9846-20 | fragment | chalky | WHITE N9 |
| HLS-077 | H2000/2763-28 | fragment | chalky | WHITE N9 |
| HLS-079 | Vats (no #) | large cone | chalky | WHITE N9 |
| HLS-080 | Vats (no #) | large cone | chalky | WHITE N9 |
| HLS-081 | Vats (B1514) | bull sculpture fragment | fine sandy crystalline | Brownish GRAY 5YR 4/1 |
| HLS-082 | H2000/9880-75 | shaped stone | fine sandy crystalline | GRAYish red purple 5RP 4/2 |
| HLS-083 | H99/9413-73 | fragment | fine sandy | Moderate reddish brown 10R 4/6 (GOLDEN group) |
| HLS-084 | H99/8387-96 | fragment | MICRITIC | Moderate yellowish brown 10YR 5/4 |
| HLS-085 | H99/8939-228 | shaped stone | crystalline | Dark yellowish brown 10YR 4/2 (BANDED group) |
| HLS-086 | H98/8331-69 | fragment | fine sandy | GRAYish red 10R 4/2 |
| HLS-087 | H98/8307-2 | shaped stone | fine sandy | Moderate reddish brown 10R 4/6 (GRAY group) |
| HLS-088 | H98/8323-12 | fragment | fine sandy | GRAYish red purple 5RP 4/2 |
| HLS-089 | H98/8324-11 | shaped | fine sandy | GRAYish red purple 5RP 4/2 |
| HLS-090 | H98/8438-8 | shaped stone | fine sandy crystalline | Brownish GRAY 5YR 4/1 |
| HLS-091 | H98/8321-1 | ringstone fragment | fine sandy crystalline | GRAYish red purple 5RP 4/2 |
| HLS-093 | Vats (T#121) | shaped stone | sandy crystalline | Dark reddish brown 10R 3/4 (GRAY group) |
| HLS-094 | Vats (T#143) | shaped stone | fine sandy crystalline | GRAYish red 10R 4/2 to Pale reddish brown 10R 5/4 |
| HLS-096 | Vats (T#99) | shaped stone | fine sandy | Moderate reddish brown 10R 4/6 (GRAY group) |
| HLS-097 | H98/8306-21 | wavy ringstone fragment | fine sandy crystalline | Brownish GRAY 5YR 4/1 |
| HLS-098 | Vats (T#105) | shaped stone | fine sandy | Pale reddish brown 10R 5/4 (GRAY group) |
| HLS-099 | Vats (T#142) | shaped stone | fine sandy crystalline | GRAY red purple 5RP 4/2 |
| HLS-100 | Vats (T#133) | shaped stone | fine sandy crystalline | Brownish GRAY 5YR 4/1 |
| HLS-101 | H98/8306-256 | fragment | sandy crystalline | GRAYish red purple 5RP 4/2 |
| HLS-102 | H98/8306-23 | shaped stone | fine sandy crystalline | Medium GRAY N5 |
| HLS-103 | H98/9724-50 | fragment | sandy crystalline | Grayish red 10R 4/2 (BANDED group) |
| HLS-104 | Vats (T#116) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-105 | Vats T#123 | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-106 | Vats (T#124) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-107 | Vats (T#125) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-108 | Vats (T#126) | shaped stone | sandy crystalline | Medium GRAY N5 |

| sample # | artifact # | artifact type | texture | color |
|---|---|---|---|---|
| HLS-109 | Vats (T#128) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-110 | Vats (T#134) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-111 | Vats (T#136) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-112 | Vats (T#138) | shaped stone | sandy crystalline | Medium GRAY N5 |
| HLS-113 | Vats (T#139) | shaped stone | sandy crystalline | Medium GRAY N5 |

# APPENDIX 11.2

## RESULTS OF ICP-MS ANALYSIS OF THE INITIAL LIMESTONE SET

Elemental data in parts per million (ppm).

| Sample | Ca | Sr | Ba | La | Ce |
|---|---|---|---|---|---|
| DLS-001 | 126265 | 111.97 | 17.37 | 11.133 | 19.082 |
| DLS-002 | 157405 | 105.69 | 9.21 | 4.446 | 8.1 |
| DLS-003 | 161388 | 115.74 | 22.57 | 10.248 | 11.392 |
| DLS-004 | 99358 | 72 | 10.81 | 5.513 | 9.442 |
| DLS-005 | 143223 | 172.17 | 2.57 | 7.791 | 11.947 |
| DLS-006 | 133571 | 87.46 | 4.77 | 8.914 | 11.397 |
| DLS-007 | 165081 | 109.55 | 14.22 | 12.909 | 16.916 |
| DLS-008 | 194331 | 144.58 | 7.54 | 8.428 | 12.008 |
| DLS-009 | 152483 | 148.9 | 17.15 | 15.346 | 23.635 |
| DLS-010 | 174448 | 142.9 | 17.94 | 12.623 | 21.246 |
| DLS-011 | 140829 | 119.04 | 10.03 | 9.405 | 15.091 |
| DLS-012 | 129642 | 103.62 | 10.05 | 9.353 | 15.044 |
| DLS-013 | 106197 | 93.09 | 16.27 | 25.333 | 40.449 |
| DLS-014 | 158871 | 110.27 | 9.86 | 5.012 | 9.196 |
| DLS-015 | 133821 | 102.24 | 4.77 | 5.654 | 7.965 |
| JLS-001 | 115093 | 94.06 | 30.71 | 8.998 | 13.122 |
| JLS-002 | 122255 | 59.73 | 12.32 | 2.566 | 5.343 |
| JLS-003 | 127799 | 75.06 | 40.12 | 14.717 | 23.336 |
| JLS-004 | 100394 | 57.25 | 23.75 | 12.64 | 22.023 |
| JLS-005 | 104493 | 52.84 | 8.71 | 2.729 | 5.638 |
| JLS-006 | 113054 | 31.39 | 13.85 | 2.641 | 5.521 |
| JLS-007 | 111399 | 36.48 | 14.41 | 2.132 | 3.672 |
| JLS-008 | 158288 | 50.41 | 22.13 | 3.14 | 6.747 |
| JLS-009 | 134817 | 50.39 | 32.36 | 2.13 | 4.57 |
| JLS-010 | 130113 | 37.68 | 19.87 | 4.837 | 8.714 |
| JLS-011 | 161734 | 54.85 | 27.52 | 4.015 | 7.23 |
| JLS-012 | 127905 | 62.45 | 14.29 | 3.529 | 6.058 |
| JLS-013 | 126719 | 42.05 | 13.62 | 2.769 | 5.856 |
| JLS-014 | 124329 | 47.82 | 10.47 | 1.97 | 3.84 |
| JLS-015 | 114492 | 43.7 | 10.35 | 1.697 | 3.288 |
| HLS-1 | 128037 | 123.43 | 6.22 | 11.757 | 20.015 |
| HLS-2 | 162785 | 130.42 | 3.18 | 7.276 | 9.281 |
| HLS-3 | 211961 | 282.91 | 1.16 | 3.589 | 6.5 |
| HLS-4 | 140026 | 106.84 | 27.59 | 1.271 | 2.319 |
| HLS-5 | 123213 | 85.05 | 14.29 | 8.217 | 10.153 |
| HLS-6 | 114826 | 57.9 | 13.55 | 4.17 | 4.939 |

# APPENDIX 11.3

# RESULTS OF INAA ANALYSIS OF THE INITIAL LIMESTONE SET

Elemental data in parts per million (ppm).

| Sample | Al | Ca | Eu | Fe | La | Lu | Mg | Mn | Sr | V |
|---|---|---|---|---|---|---|---|---|---|---|
| DLS-001 | 2953 | 387460 | 1.33 | 34363 | 27.1 | 0.333 | 1375 | 1254 | 226.1 | 85.5 |
| DLS-002 | 2343 | 408878 | 0.35 | 29846 | 9.7 | 0.099 | 838 | 477 | 165.6 | 22.7 |
| DLS-003 | 6115 | 335005 | 1.68 | 115292 | 25.8 | 0.461 | 1828 | 837 | 111.7 | 84.2 |
| DLS-004 | 2385 | 330933 | 1.11 | 72417 | 37.3 | 0.184 | 980 | 1447 | 137.3 | 96.2 |
| DLS-005 | 1743 | 422005 | 0.49 | 11532 | 9.7 | 0.095 | 800 | 506 | 114 | 18.3 |
| DLS-006 | 1613 | 412840 | 0.44 | 15918 | 8.9 | 0.095 | 538 | 500 | 60.4 | 13.7 |
| DLS-007 | 1062 | 385372 | 0.30 | 8931 | 6.1 | 0.066 | 730 | 397 | 101.2 | 15.1 |
| DLS-008 | 1515 | 386199 | 0.37 | 19605 | 8.1 | 0.087 | 603 | 458 | 158 | 18 |
| DLS-009 | 1084 | 375720 | 0.32 | 12390 | 6.6 | 0.061 | 592 | 506 | 206.2 | 11.2 |
| DLS-010 | 3706 | 375126 | 0.78 | 32575 | 12.8 | 0.149 | 713 | 511 | 85.4 | 43 |
| DLS-011 | 1572 | 375008 | 0.31 | 8983 | 8.6 | 0.079 | 689 | 474 | 141.9 | 18.8 |
| DLS-012 | 835 | 380274 | 0.32 | 29853 | 10.2 | 0.069 | 741 | 776 | 513.9 | 18.6 |
| DLS-013 | 1484 | 371777 | 0.39 | 20953 | 9.2 | 0.087 | 641 | 434 | 140.2 | 16.3 |
| DLS-014 | 947 | 388769 | 0.30 | 9908 | 8.9 | 0.059 | 623 | 388 | 207.2 | 12.3 |
| DLS-015 | 1162 | 426359 | 0.27 | 10819 | 7.2 | 0.061 | 827 | 496 | 168.7 | 14 |
| JLS-1 | 3784 | 342954 | 1.66 | 69959 | 31.0 | 0.399 | 1627 | 1197 | 442.8 | 103.1 |
| JLS-2 | 3274 | 405748 | 0.60 | 11131 | 8.9 | 0.14 | 1000 | 633 | 593.1 | 62.3 |
| JLS-3 | 1527 | 399216 | 0.77 | 14250 | 19.4 | 0.208 | 1509 | 885 | 552.4 | 23.5 |
| JLS-4 | 13750 | 276295 | 0.78 | 10512 | 21.3 | 0.171 | 1430 | 1225 | 671.7 | 34.8 |
| JLS-5 | 2659 | 379185 | 0.93 | 14376 | 19.0 | 0.215 | 1827 | 921 | 973.9 | 37.6 |
| JLS-6 | 2008 | 410254 | 1.04 | 12230 | 23.9 | 0.246 | 958 | 691 | 363.4 | 28 |
| JLS-7 | 2350 | 393629 | 1.04 | 12776 | 27.4 | 0.225 | 1057 | 691 | 317.9 | 26.6 |
| JLS-8 | 1873 | 336543 | 0.60 | 12989 | 18.0 | 0.147 | 1184 | 644 | 412.8 | 13.6 |
| JLS-9 | 4388 | 289262 | 1.47 | 49190 | 33.8 | 0.445 | 1347 | 1083 | 405.9 | 111.2 |
| JLS-11 | 3584 | 311337 | 1.14 | 66718 | 26.6 | 0.347 | 1447 | 1129 | 381.6 | 87 |
| JLS-12 | 3526 | 304023 | 1.15 | 53360 | 30.9 | 0.344 | 1528 | 924 | 444.2 | 80.1 |
| JLS-13 | 3264 | 300605 | 1.20 | 81419 | 31.2 | 0.332 | 1094 | 1274 | 360 | 95.4 |
| JLS-14 | 3627 | 317203 | 0.53 | 38173 | 8.5 | 0.213 | 1173 | 730 | 775.8 | 98.2 |
| JLS-15 | 1794 | 350108 | 0.60 | 12216 | 16.7 | 0.129 | 1022 | 648 | 363.7 | 12.8 |
| HLS-1 | 4119 | 344665 | 1.78 | 14462 | 7.1 | 0.071 | 1773 | 784 | 650.4 | 99.4 |
| HLS-2 | 1811 | 396031 | 1.02 | 16654 | 7.7 | 0.088 | 1539 | 589 | 499.2 | 27.1 |
| HLS-3 | 254 | 391304 | 0.85 | 178904 | 27.4 | 0.241 | 1128 | 285 | 738.8 | 307.2 |
| HLS-4 | 1245 | 399206 | 0.06 | 14667 | 7.1 | 0.071 | 1101 | 563 | 313.2 | 15.7 |
| HLS-5 | 1382 | 368002 | 0.61 | 11476 | 16.1 | 0.123 | 1572 | 623 | 213.9 | 22.7 |
| HLS-6 | 1251 | 416175 | 0.49 | 10618 | 12.5 | 0.102 | 1165 | 682 | 159.3 | 13.3 |

# APPENDIX 11.4

## RESULTS OF ICP-AES ANALYSIS OF THE EXPANDED GEOLOGIC LIMESTONE SAMPLE SET

Elemental data in parts per million (ppm).

| Sample# | Region | Location | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|
| DLS-001 | Kutch/Khadir Island | Harappan quarry | 331063 | 112.13 | 360 | 17894 | 2726 |
| DLS-002 | Kutch/Khadir Island | Harappan quarry | 397579 | 283.45 | 244 | 7753 | 1962 |
| DLS-003 | Kutch/Khadir Island | Harappan quarry | 367466 | 108.52 | 287 | 6714 | 1971 |
| DLS-004 | Kutch/Khadir Island | Harappan quarry | 226195 | 50.21 | 168 | 4987 | 1195 |
| DLS-005 | Kutch/Khadir Island | Harappan quarry | 353926 | 145.2 | 532 | 12601 | 2985 |
| DLS-006 | Kutch/Khadir Island | Harappan quarry | 365226 | 20.57 | 269 | 7637 | 1831 |
| DLS-007 | Kutch/Khadir Island | Harappan quarry | 367289 | 117.81 | 276 | 7611 | 1913 |
| DLS-008 | Kutch/Khadir Island | Harappan quarry | 390535 | 98.91 | 323 | 8403 | 2034 |
| DLS-009 | Kutch/Khadir Island | Harappan quarry | 277943 | 152.26 | 272 | 22480 | 2544 |
| DLS-010 | Kutch/Khadir Island | Harappan quarry | 351698 | 63.38 | 312 | 8230 | 3493 |
| DLS-011 | Kutch/Khadir Island | Harappan quarry | 337063 | 37.82 | 310 | 15197 | 2427 |
| DLS-012 | Kutch/Khadir Island | Harappan quarry | 336488 | 49.62 | 311 | 10661 | 2502 |
| DLS-013 | Kutch/Khadir Island | Harappan quarry | 379955 | 44.2 | 361 | 14142 | 2911 |
| DLS-014 | Kutch/Khadir Island | Harappan quarry | 359622 | 40.87 | 242 | 25333 | 2259 |
| DLS-015 | Kutch/Khadir Island | Harappan quarry | 415959 | 28.04 | 348 | 8111 | 2205 |
| DLS-016 | Kutch/Khadir Island | Harappan quarry | 434542 | 41.27 | 300 | 4813 | 2623 |
| DLS-017 | Kutch/Khadir Island | Harappan quarry | 463583 | 37.95 | 377 | 6323 | 3332 |
| DLS-018 | Kutch/Khadir Island | Harappan quarry | 299004 | 143.82 | 500 | 23211 | 3162 |
| DLS-019 | Kutch/Khadir Island | Harappan quarry | 462375 | 30.16 | 360 | 8223 | 3060 |
| DLS-020 | Kutch/Khadir Island | Harappan quarry | 441406 | 26.83 | 354 | 8192 | 3087 |
| DLS-021 | Kutch/Khadir Island | Harappan quarry | 448342 | 22.67 | 344 | 8070 | 3074 |
| DLS-022 | Kutch/Khadir Island | Harappan quarry | 407298 | 133.77 | 298 | 15167 | 3363 |
| DLS-023 | Kutch/Khadir Island | Harappan quarry | 428826 | 29.34 | 299 | 27596 | 2596 |
| DLS-024 | Kutch/Khadir Island | Harappan quarry | 410185 | 26.42 | 378 | 11325 | 2849 |
| DLS-025 | Kutch/Khadir Island | Harappan quarry | 352952 | 37.39 | 287 | 8285 | 2489 |
| DLS-026 | Kutch/Khadir Island | Harappan quarry | 387533 | 57.5 | 262 | 7264 | 2382 |
| DLS-027 | Kutch/Khadir Island | Harappan quarry | 374897 | 29.57 | 393 | 14845 | 5600 |
| DLS-028 | Kutch/Khadir Island | Harappan quarry | 276460 | 44.4 | 201 | 2436 | 1682 |
| DLS-029 | Kutch/Khadir Island | Harappan quarry | 275510 | 18.45 | 243 | 1785 | 2504 |
| DLS-030 | Kutch/Khadir Island | Harappan quarry | 259520 | 21.69 | 230 | 1748 | 1971 |
| LTH-001 | Kutch/Khadir Island | Limdiwali Tari | 341565 | 13.26 | 264 | 2217 | 1867 |
| LTH-002 | Kutch/Khadir Island | Limdiwali Tari | 332137 | 37.03 | 313 | 1550 | 2141 |
| LTH-003 | Kutch/Khadir Island | Limdiwali Tari | 313953 | 41.56 | 225 | 1207 | 1645 |
| LTH-004 | Kutch/Khadir Island | Limdiwali Tari | 328832 | 58.41 | 270 | 1367 | 2110 |

| Sample# | Region | Location | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|
| LTH-005 | Kutch/Khadir Island | Limdiwali Tari | 341857 | 23.9 | 264 | 2835 | 2180 |
| LTH-006 | Kutch/Khadir Island | Limdiwali Tari | 319302 | 56.21 | 399 | 1906 | 1999 |
| LTH-007 | Kutch/Khadir Island | Limdiwali Tari | 305745 | 29.39 | 245 | 1654 | 1985 |
| LTH-008 | Kutch/Khadir Island | Limdiwali Tari | 317857 | 34.49 | 258 | 2223 | 1827 |
| LTH-009 | Kutch/Khadir Island | Limdiwali Tari | 301952 | 118 | 241 | 1183 | 1262 |
| LTH-010 | Kutch/Khadir Island | Limdiwali Tari | 310043 | 18.19 | 247 | 1494 | 1915 |
| LTH-011 | Kutch/Khadir Island | Limdiwali Tari | 318406 | 105 | 255 | 1314 | 1487 |
| LTH-012 | Kutch/Khadir Island | Limdiwali Tari | 316330 | 38.11 | 277 | 1555 | 2025 |
| LTH-013 | Kutch/Khadir Island | Limdiwali Tari | 310133 | 28.79 | 241 | 1908 | 1696 |
| LTH-014 | Kutch/Khadir Island | Limdiwali Tari | 299548 | 50.96 | 233 | 1919 | 1841 |
| LTH-015 | Kutch/Khadir Island | Limdiwali Tari | 321422 | 57.56 | 391 | 1836 | 2027 |
| P-001 | Kutch/Pachchham I. | near Juni Kuran | 268205 | 35.22 | 337 | 2864 | 2466 |
| P-002 | Kutch/Pachchham I. | near Juni Kuran | 224788 | 35.53 | 263 | 2904 | 1674 |
| P-003 | Kutch/Pachchham I. | near Juni Kuran | 330452 | 3.53 | 354 | 2205 | 1476 |
| P-004 | Kutch/Pachchham I. | near Juni Kuran | 318651 | 7.23 | 343 | 1226 | 1401 |
| P-005 | Kutch/Pachchham I. | near Juni Kuran | 303873 | 18.25 | 271 | 1296 | 1309 |
| P-006 | Kutch/Pachchham I. | near Juni Kuran | 333266 | 6.18 | 341 | 1409 | 1392 |
| P-007 | Kutch/Pachchham I. | near Juni Kuran | 240965 | 127 | 323 | 2778 | 36712 |
| P-008 | Kutch/Pachchham I. | near Juni Kuran | 316300 | 41.45 | 293 | 1454 | 1542 |
| P-009 | Kutch/Pachchham I. | near Juni Kuran | 309071 | 180 | 404 | 2448 | 2067 |
| P-010 | Kutch/Pachchham I. | near Juni Kuran | 283928 | 53.86 | 285 | 1475 | 1418 |
| P-011 | Kutch/Pachchham I. | near Juni Kuran | 267741 | 11.99 | 446 | 4733 | 1760 |
| P-012 | Kutch/Pachchham I. | near Juni Kuran | 207755 | 10.99 | 261 | 3129 | 1271 |
| P-013 | Kutch/Pachchham I. | near Juni Kuran | 300556 | 66.75 | 245 | 12203 | 1602 |
| P-014 | Kutch/Pachchham I. | near Juni Kuran | 199705 | 10.85 | 329 | 4454 | 1526 |
| P-015 | Kutch/Pachchham I. | near Juni Kuran | 133109 | 6.57 | 97 | 1871 | 658 |
| P-016 | Kutch/Pachchham I. | near Juni Kuran | 135284 | 13.75 | 226 | 2718 | 927 |
| P-017 | Kutch/Pachchham I. | near Juni Kuran | 133096 | 5.95 | 178 | 5115 | 1278 |
| P-018 | Kutch/Pachchham I. | near Juni Kuran | 233959 | 23.49 | 200 | 12019 | 1946 |
| P-019 | Kutch/Pachchham I. | near Juni Kuran | 187688 | 12.33 | 218 | 3294 | 1276 |
| P-020 | Kutch/Pachchham I. | near Juni Kuran | 125505 | 16.02 | 206 | 1921 | 979 |
| JLS-001 | Rajasthan-Jaisalmer | Mool Sagar Khan | 389975 | 319 | 316 | 10946 | 2503 |
| JLS-002 | Rajasthan-Jaisalmer | Jethway | 414757 | 33.63 | 262 | 6327 | 1794 |
| JLS-003 | Rajasthan-Jaisalmer | Mool Sagar Khan | 338291 | 131 | 241 | 15292 | 2486 |
| JLS-004 | Rajasthan-Jaisalmer | Mool Sagar Khan | 309427 | 59.57 | 239 | 13406 | 1659 |
| JLS-005 | Rajasthan-Jaisalmer | Jethway | 376232 | 19.86 | 208 | 3827 | 1400 |
| JLS-006 | Rajasthan-Jaisalmer | Jethway | 405651 | 24.06 | 127 | 2981 | 935 |
| JLS-007 | Rajasthan-Jaisalmer | Jethway | 386713 | 58.17 | 141 | 3606 | 1061 |
| JLS-008 | Rajasthan-Jaisalmer | Jethway | 359132 | 71.78 | 135 | 3316 | 955 |
| JLS-009 | Rajasthan-Jaisalmer | Jethway | 359295 | 128.9 | 155 | 3222 | 1024 |
| JLS-010 | Rajasthan-Jaisalmer | Mool Sagar Khan | 332607 | 62.93 | 105 | 5300 | 979 |

| Sample# | Region | Location | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|
| JLS-011 | Rajasthan-Jaisalmer | Mool Sagar Khan | 387637 | 50.9 | 151 | 3345 | 1190 |
| JLS-012 | Rajasthan-Jaisalmer | Mool Sagar Khan | 367296 | 27.97 | 198 | 3649 | 1623 |
| JLS-013 | Rajasthan-Jaisalmer | Jethway | 374355 | 27.64 | 135 | 3439 | 955 |
| JLS-014 | Rajasthan-Jaisalmer | Jethway | 354914 | 43.08 | 150 | 3901 | 943 |
| JLS-015 | Rajasthan-Jaisalmer | Jethway | 383276 | 17.98 | 164 | 4437 | 1012 |
| JLS-016 | Rajasthan-Jaisalmer | Jethway | 417839 | 158.6 | 243 | 4353 | 2086 |
| JLS-017 | Rajasthan-Jaisalmer | Jethway | 464355 | 76.82 | 190 | 3566 | 2016 |
| JLS-018 | Rajasthan-Jaisalmer | Jethway | 515504 | 20.29 | 281 | 3148 | 2163 |
| JLS-019 | Rajasthan-Jaisalmer | Jethway | 462682 | 96.23 | 208 | 3483 | 2814 |
| JLS-020 | Rajasthan-Jaisalmer | Jethway | 277235 | 85.01 | 152 | 1140 | 1468 |
| JLS-021 | Rajasthan-Jaisalmer | Jethway | 284176 | 47.59 | 117 | 729 | 1161 |
| JLS-022 | Rajasthan-Jaisalmer | Jethway | 303138 | 24.64 | 134 | 665 | 1143 |
| JLS-023 | Rajasthan-Jaisalmer | Habur | 271288 | 66.41 | 129 | 630 | 1146 |
| JLS-024 | Rajasthan-Jaisalmer | Habur | 280923 | 38.85 | 167 | 932 | 1283 |
| JLS-025 | Rajasthan-Jaisalmer | Habur | 314692 | 43.75 | 199 | 2709 | 1727 |
| JLS-026 | Rajasthan-Jaisalmer | Habur | 276003 | 30.13 | 142 | 786 | 1329 |
| JLS-027 | Rajasthan-Jaisalmer | Habur | 220158 | 32.1 | 127 | 647 | 1076 |
| JLS-028 | Rajasthan-Jaisalmer | Habur | 279734 | 27.42 | 148 | 1177 | 1310 |
| JLS-029 | Rajasthan-Jaisalmer | Habur | 258038 | 29.78 | 150 | 3109 | 1234 |
| JLS-030 | Rajasthan-Jaisalmer | Habur | 371593 | 31.4 | 151 | 2788 | 1071 |
| JLS-031 | Rajasthan-Jaisalmer | Habur | 273143 | 59.61 | 197 | 2147 | 1516 |
| JLS-032 | Rajasthan-Jaisalmer | Habur | 346034 | 40.67 | 152 | 1133 | 996 |
| JLS-033 | Rajasthan-Jaisalmer | Habur | 296821 | 39.86 | 191 | 1005 | 1410 |
| JLS-034 | Rajasthan-Jaisalmer | Habur | 338900 | 79.17 | 231 | 1731 | 1615 |
| JLS-035 | Rajasthan-Jaisalmer | Habur | 348362 | 32.21 | 107 | 788 | 868 |
| JLS-036 | Rajasthan-Jaisalmer | Mool Sagar Khan | 308686 | 64.13 | 146 | 1019 | 1287 |
| JLS-037 | Rajasthan-Jaisalmer | Mool Sagar Khan | 340784 | 37.42 | 127 | 826 | 948 |
| JLS-038 | Rajasthan-Jaisalmer | Mool Sagar Khan | 140094 | 77.9 | 104 | 694 | 622 |
| JLS-039 | Rajasthan-Jaisalmer | Mool Sagar Khan | 337400 | 20.66 | 103 | 730 | 855 |
| JLS-040 | Rajasthan-Jaisalmer | Mool Sagar Khan | 296738 | 31.69 | 96 | 880 | 1194 |
| JLS-041 | Rajasthan-Jaisalmer | Jethway | 337982 | 61.65 | 219 | 2024 | 1631 |
| JLS-042 | Rajasthan-Jaisalmer | Jethway | 347986 | 42.89 | 153 | 1139 | 996 |
| JLS-043 | Rajasthan-Jaisalmer | Jethway | 361109 | 27.27 | 158 | 1155 | 1069 |
| JLS-044 | Rajasthan-Jaisalmer | Habur | 340108 | 28.28 | 209 | 1196 | 1441 |
| JLS-045 | Rajasthan-Jaisalmer | Habur | 344640 | 21.11 | 146 | 1114 | 1003 |
| JLS-046 | Rajasthan-Jaisalmer | Habur | 350774 | 20.56 | 148 | 1136 | 1022 |
| JLS-047 | Rajasthan-Jaisalmer | Habur | 323617 | 36.96 | 120 | 834 | 885 |
| JLS-048 | Rajasthan-Jaisalmer | Habur | 330826 | 48.3 | 154 | 1077 | 1157 |
| JLS-049 | Rajasthan-Jaisalmer | Habur | 343405 | 11.19 | 192 | 745 | 1297 |
| JLS-050 | Rajasthan-Jaisalmer | Habur | 319604 | 73.75 | 234 | 2245 | 1819 |
| JLS-051 | Rajasthan-Jaisalmer | Amar Sagar | 208001 | 107.12 | 202 | 1003 | 1526 |

| Sample# | Region | Location | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|
| JLS-052 | Rajasthan-Jaisalmer | Amar Sagar | 348387 | 33.19 | 130 | 886 | 951 |
| JLS-053 | Rajasthan-Jaisalmer | Amar Sagar | 318835 | 33.13 | 135 | 970 | 992 |
| JLS-054 | Rajasthan-Jaisalmer | Amar Sagar | 290826 | 37.75 | 112 | 941 | 1220 |
| JLS-055 | Rajasthan-Jaisalmer | Amar Sagar | 306224 | 46.43 | 182 | 1552 | 1448 |
| JLS-056 | Rajasthan-Jaisalmer | Amar Sagar | 309604 | 37.19 | 194 | 1042 | 1512 |
| JLS-057 | Rajasthan-Jaisalmer | Amar Sagar | 321373 | 30.57 | 167 | 1056 | 1144 |
| JLS-058 | Rajasthan-Jaisalmer | Amar Sagar | 331589 | 48.96 | 219 | 1705 | 1744 |
| JLS-059 | Rajasthan-Jaisalmer | Amar Sagar | 334251 | 38.44 | 189 | 1237 | 1362 |
| JLS-060 | Rajasthan-Jaisalmer | Amar Sagar | 474903 | 46.64 | 190 | 2762 | 1763 |
| RHLS-001 | Sindh - Rohri Hills | Nara near Thari | 487384 | 60.82 | 691 | 320 | 2125 |
| RHLS-002 | Sindh - Rohri Hills | Nara near Thari | 519208 | 29.14 | 925 | 524 | 2366 |
| RHLS-003 | Sindh - Rohri Hills | Kandarki | 500046 | 27.45 | 870 | 341 | 1622 |
| RHLS-004 | Sindh - Rohri Hills | Adam Sultan | 493414 | 30.81 | 1540 | 873 | 2265 |
| RHLS-005 | Sindh - Rohri Hills | Adam Sultan | 452711 | 23.79 | 2074 | 1053 | 6753 |
| RHLS-006 | Sindh - Rohri Hills | Rohri | 507840 | 23.01 | 746 | 334 | 1713 |
| RHLS-007 | Sindh - Rohri Hills | Rohri | 499546 | 21.32 | 597 | 4468 | 1451 |
| RHLS-008 | Sindh - Rohri Hills | Kot Diji | 493205 | 36.77 | 984 | 730 | 1946 |
| RHLS-009 | Sindh - Rohri Hills | Kot Diji | 512351 | 62.04 | 1270 | 906 | 1965 |
| RHLS-010 | Sindh - Rohri Hills | Kot Diji | 538777 | 46.84 | 1447 | 834 | 2510 |
| RHLS-011 | Sindh - Rohri Hills | Kot Diji | 522827 | 36.52 | 1282 | 686 | 2437 |
| RHLS-012 | Sindh - Rohri Hills | Kot Diji | 479314 | 40.9 | 1363 | 767 | 3787 |
| RHLS-013 | Sindh - Rohri Hills | Kot Diji | 486996 | 28.03 | 1707 | 769 | 2200 |
| RHLS-014 | Sindh - Rohri Hills | Kot Diji | 506259 | 41.62 | 1251 | 545 | 1737 |
| RHLS-015 | Sindh - Rohri Hills | Kot Diji | 502324 | 36.76 | 654 | 749 | 1642 |
| RHLS-016 | Sindh - Rohri Hills | Kot Diji | 495404 | 36.62 | 618 | 487 | 1548 |
| RHLS-017 | Sindh - Rohri Hills | Adam Sultan | 451690 | 22.28 | 1968 | 913 | 6821 |
| RHLS-018 | Sindh - Rohri Hills | Nara near Thari | 509239 | 27.13 | 865 | 567 | 2342 |
| RHLS-019 | Sindh - Rohri Hills | Kot Diji | 506344 | 50.86 | 769 | 629 | 1676 |
| RHLS-020 | Sindh - Rohri Hills | Kot Diji | 498539 | 57.28 | 1695 | 557 | 2039 |
| RHLS-021 | Sindh - Rohri Hills | Kot Diji | 475943 | 45.82 | 1825 | 1214 | 2649 |
| RHLS-022 | Sindh - Rohri Hills | Kot Diji | 509014 | 31.26 | 1203 | 521 | 2269 |
| RHLS-023 | Sindh - Rohri Hills | Kot Diji | 491319 | 34.7 | 978 | 571 | 1723 |
| RHLS-024 | Sindh - Rohri Hills | Kot Diji | 488056 | 39.32 | 1215 | 865 | 2242 |
| RHLS-025 | Sindh - Rohri Hills | Kot Diji | 493299 | 75.23 | 1449 | 596 | 2111 |
| GJLS-1 | Gujarat - Junagadh | Adityana | 486320 | 53.6 | 2214 | 1996 | 5618 |
| GJLS-2 | Gujarat - Junagadh | Adityana | 427030 | 76.03 | 857 | 2799 | 4893 |
| GJLS-3 | Gujarat - Junagadh | Adityana | 431957 | 103.49 | 1928 | 4502 | 7307 |
| GJLS-4 | Gujarat - Junagadh | Adityana | 416530 | 75.67 | 1028 | 3389 | 5449 |
| GJLS-5 | Gujarat - Junagadh | Adityana | 464294 | 114.38 | 2754 | 3892 | 7937 |
| LPLS-1 | Balochistan - Loralai | Loralai Town | 423434 | 80.54 | 886 | 1252 | 1909 |
| LPLS-2 | Balochistan - Loralai | Loralai Town | 452280 | 80.01 | 957 | 1094 | 1734 |

| Sample# | Region | Location | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|
| LPLS-3 | Balochistan - Loralai | Loralai Town | 502506 | 90.63 | 1096 | 1241 | 1913 |
| KRLS-001 | Sindh - Kirthar | Ranikot | 455785 | 334.21 | 679 | 8764 | 2867 |
| KRLS-002 | Sindh - Kirthar | Ranikot | 446144 | 619.91 | 631 | 7162 | 2547 |

# APPENDIX 11.5

## RESULTS OF ICP-AES ANALYSIS OF THE EXPANDED HARAPPAN LIMESTONE SAMPLE SET

Elemental data in parts per million (ppm).

MSK = Mool Sagar Khan (Jaisalmer Formation)

| Sample# | Mound | Trench | Period | Probable geologic provenience | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|---|---|
| HLS-001 | AB-E | 53 | 3+ | Pachchham Fm. – Khadir quarry | 357994 | 16.91 | 400.1 | 23213 | 2541 |
| HLS-002 | n/a | n/a | n/a | Pachchham Fm. – Juni Kuran | 379903 | 7.59 | 335 | 7285 | 2099 |
| HLS-003 | E | 54 | 3+ | Unclear at this time * not Rohri Hills | 398604 | 0.01 | 600.4 | 773 | 1177 |
| HLS-004 | E | 56 | 3+ | Pachchham Fm. – Khadir quarry | 406386 | 139.78 | 353.1 | 7384 | 2098 |
| HLS-005 | E | 54 | 3+ | Pachchham Fm. – Khadir * possibly MSK | 373805 | 88.14 | 296.2 | 8190 | 2231 |
| HLS-006 | AB | 31 | 3+ | Pachchham Fm. – Khadir quarry | 405231 | 34.94 | 273.8 | 9520 | 1784 |
| HLS-007 | n/a | n/a | n/a | Pachchham Fm. – Khadir quarry | 403443 | 33.5 | 366.1 | 9868 | 3585 |
| HLS-008 | ET | Thana | n/a | Pachchham Fm. – Khadir quarry | 455098 | 30.71 | 376.6 | 8306 | 3035 |
| HLS-009 | E | 36 | 3C | Sindh – Rohri Hills | 522709 | 29.77 | 668.8 | 635 | 2068 |
| HLS-010 | E | 46 | 3C | Sindh – Rohri Hills | 536330 | 119.5 | 255.7 | 407 | 2345 |
| HLS-011 | ET | surf | 3+ | Pachchham Fm. – Khadir quarry | 471586 | 30.01 | 337.9 | 6470 | 2722 |
| HLS-012 | E | 7 | 3+ | Pachchham Fm. – Khadir quarry | 430884 | 24.95 | 381.1 | 7914 | 3381 |
| HLS-013 | E | 8 | 3C | Pachchham Fm. – Khadir quarry | 458575 | 29.32 | 344.2 | 8126 | 2745 |
| HLS-014 | E | 8 | 3C | Pachchham Fm. – Khadir quarry | 466838 | 25.84 | 336.1 | 6934 | 3170 |
| HLS-015 | AB | mosque | 3+ | Pachchham Fm. – Khadir * possibly MSK | 502028 | 29.49 | 318 | 4894 | 2614 |
| HLS-016 | E | 7_8 | 3C | Pachchham Fm. – Khadir quarry | 469517 | 33.91 | 427.2 | 8303 | 3965 |
| HLS-017 | ET | 28 | 3C | Pachchham Fm. – Juni Kuran | 475755 | 52.13 | 450.5 | 5945 | 2931 |
| HLS-018 | E | 7_8 | 3+ | Pachchham Fm. – Khadir quarry | 433480 | 39.56 | 318.6 | 16011 | 3311 |
| HLS-019 | E | 7_8 | 3+ | Pachchham Fm. – Khadir quarry | 436903 | 163.6 | 344.1 | 8640 | 3280 |
| HLS-020 | E | 7_8 | 3C | Jaisalmer Fm. – Mool Sagar Khan | 481506 | 94.33 | 302.4 | 7358 | 2440 |
| HLS-021 | AB | 31 | 3C | Pachchham Fm. – Khadir quarry | 437755 | 46.3 | 329.3 | 7861 | 2816 |
| HLS-022 | E | 36 | 3+ | Pachchham Fm. – Juni Kuran | 455274 | 36.98 | 516.1 | 7217 | 4976 |
| HLS-023 | F | 37 | 3+ | Jaisalmer Fm. – Mool Sagar Khan | 419655 | 105.34 | 292.3 | 7727 | 2588 |
| HLS-024 | AB | 39 | 3+ | Pachchham Fm. – Khadir * possibly MSK | 294439 | 33.41 | 199.3 | 3960 | 1892 |
| HLS-025 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 495416 | 58.79 | 388.8 | 7411 | 2438 |
| HLS-026 | AB | 39 | 3C | Pachchham Fm. – Limdiwali Tari | 489313 | 31.27 | 372.7 | 4957 | 2606 |

| Sample# | Mound | Trench | Period | Probable geologic provenience | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|---|---|
| HLS-027 | AB | 39 | 3C | Pachchham Fm. – Khadir quarry | 509927 | 23.13 | 341.5 | 6270 | 2996 |
| HLS-028 | AB | 39 | 3C | Pachchham Fm. – Juni Kuran | 477468 | 24.12 | 363 | 4559 | 2596 |
| HLS-029 | AB | 39 | 3C | Pachchham Fm. – Khadir quarry | 418869 | 49.56 | 524.4 | 13356 | 3401 |
| HLS-030 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 493072 | 49.68 | 368.9 | 9005 | 2944 |
| HLS-031 | AB | 39 | 3C | Pachchham Fm. – Khadir quarry | 426012 | 62.91 | 370.8 | 13621 | 3087 |
| HLS-032 | AB | 39 | 3C | Pachchham Fm. – Khadir quarry | 432848 | 29.21 | 310.5 | 6001 | 2539 |
| HLS-033 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 449283 | 21.94 | 299.4 | 4610 | 2615 |
| HLS-034 | AB | 39 | 3C | Pachchham Fm. – Khadir quarry | 411862 | 23.31 | 307.6 | 7671 | 3188 |
| HLS-035 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 462867 | 55.6 | 462.7 | 6686 | 2428 |
| HLS-036 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 419103 | 29.07 | 404.5 | 8677 | 4373 |
| HLS-037 | F | 43 | 3C | Pachchham Fm. – Khadir quarry | 409903 | 34.95 | 353 | 14722 | 3562 |
| HLS-038 | F | 43 | 3C | Pachchham Fm. – Khadir<br>* possibly MSK | 455116 | 25.57 | 294.6 | 5114 | 2532 |
| HLS-039 | E | 54 | 3+ | Jaisalmer Fm. – Mool Sagar Khan | 491088 | 75.53 | 333.8 | 6808 | 2670 |
| HLS-040 | E | 56 | 3+ | Pachchham Fm. – Khadir quarry | 429730 | 60.62 | 309.6 | 11222 | 2629 |
| HLS-041 | AB | B | 3C+ | Pachchham Fm. – Khadir<br>* possibly MSK | 490547 | 28.21 | 330.6 | 7478 | 2958 |
| HLS-042 | AB | B | 3C+ | Pachchham Fm. – Khadir<br>* possibly MSK | 379237 | 36.78 | 258.8 | 4079 | 2304 |
| HLS-043 | AB | B | 3C+ | Jaisalmer Fm. – Mool Sagar Khan | 449342 | 53.06 | 259.9 | 7175 | 2455 |
| HLS-044 | AB | B | 3C+ | Pachchham Fm. – Khadir<br>* possibly MSK | 460706 | 136.71 | 386.5 | 6080 | 2930 |
| HLS-045 | AB | B | 3C+ | Pachchham Fm. – Khadir quarry | 499251 | 24.02 | 365.4 | 5328 | 2922 |
| HLS-046 | AB | B | 3C+ | Jaisalmer Fm. – Mool Sagar Khan | 497680 | 283.14 | 435.5 | 5755 | 3343 |
| HLS-047 | AB | B | 3C+ | Jaisalmer Fm. – Mool Sagar Khan | 454710 | 147.01 | 347 | 7952 | 3380 |
| HLS-048 | AB | 39 | 3+ | Jaisalmer Fm. – Mool Sagar Khan | 470980 | 168.86 | 267.6 | 10698 | 2480 |
| HLS-049 | AB | 38 | 3+ | Pachchham Fm. – Khadir<br>* possibly MSK | 489322 | 54.49 | 471.8 | 10000 | 3130 |
| HLS-050 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 467789 | 51.62 | 431.6 | 7392 | 2739 |
| HLS-051 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 519683 | 248.09 | 584.6 | 4485 | 1885 |
| HLS-052 | E | 54 | 3+ | Unclear at this time * not Rohri Hills | 542850 | 268.41 | 565.6 | 1639 | 1773 |
| HLS-053 | E | 54 | 3+ | Unclear at this time * not Rohri Hills | 540505 | 26.7 | 663 | 749 | 2107 |
| HLS-054 | ET | 28 | 3+ | Sindh – Rohri Hills | 12058.4 | 141.01 | 62.5 | 2785 | 747 |
| HLS-055 | E | 8 | 3C | Unclear at this time * not Rohri Hills | 491707 | 30.58 | 578.2 | 1890 | 6025 |
| HLS-056 | ET | 10W | 3+ | Pachchham Fm. – Juni Kuran | 514765 | 101.62 | 622.4 | 865 | 2230 |
| HLS-057 | E | 36 | 3+ | Sindh – Rohri Hills | 527199 | 66.14 | 481.4 | 1157 | 1777 |

| Sample# | Mound | Trench | Period | Probable geologic provenience | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|---|---|
| HLS-058 | E | 7_8 | 3C | Sindh – Rohri Hills | 54114.8 | 171.38 | 108.2 | 589 | 732 |
| HLS-060 | ET | 19W | 3C | Sindh – Rohri Hills | 529073 | 173.03 | 778.9 | 476 | 2123 |
| HLS-061 | AB | 39 | 3+ | Sindh – Rohri Hills | 262116 | 43.52 | 375.6 | 400 | 1076 |
| HLS-062 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 482366 | 66.02 | 643.7 | 8119 | 3906 |
| HLS-063 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 483640 | 105.46 | 734.6 | 8454 | 4397 |
| HLS-064 | AB | B | 3C+ | Pachchham Fm. – Khadir quarry | 454805 | 43.39 | 402 | 10315 | 3249 |
| HLS-065 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 494695 | 38.9 | 539.7 | 7560 | 4804 |
| HLS-066 | E | 11 | 3C | Pachchham Fm. – Juni Kuran | 527899 | 193.84 | 968.2 | 9021 | 4597 |
| HLS-067 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 534131 | 36.48 | 869.1 | 7237 | 3978 |
| HLS-068 | AB | 39 | 3+ | Unclear at this time * not Rohri Hills | 152550 | 138.23 | 492.7 | 47100 | 5491 |
| HLS-069 | AB | 39 | 3+ | Pachchham Fm. – Khadir quarry | 526037 | 30.59 | 381.4 | 6143 | 3131 |
| HLS-071 | F | 43 | 3C | Unclear * possibly Rohri Hills or Parh Fm. | 557303 | 60.45 | 1305 | 447 | 2686 |
| HLS-072 | F | 43 | 3+ | Unclear * possibly Rohri Hills or Parh Fm. | 510501 | 32.98 | 1210.7 | 262 | 4577 |
| HLS-073 | n/a | n/a | 3C+ | Unclear * possibly Rohri Hills or Parh Fm. | 493182 | 30.71 | 572.4 | 294 | 2191 |
| HLS-075 | E | 55 | 3C | Unclear * possibly Rohri Hills or Parh Fm. | 554604 | 53.8 | 1180.9 | 192 | 2778 |
| HLS-076 | E | 43 | 3C | Unclear * possibly Rohri Hills or Parh Fm. | 498653 | 30.81 | 1839.4 | 300 | 3332 |
| HLS-077 | E | 55 | 3C | Unclear * possibly Rohri Hills or Parh Fm. | 502045 | 61.41 | 1217.6 | 217 | 2585 |
| HLS-079 | AB | Vats III & IV | 3C+ | Unclear * possibly Rohri Hills or Parh Fm. | 417142 | 32.67 | 422.1 | 306 | 1749 |
| HLS-080 | AB | Vats III & IV | 3C+ | Unclear * possibly Rohri Hills or Parh Fm. | 518853 | 46.43 | 556.3 | 397 | 2229 |
| HLS-081 | AB | B | 3C+ | Pachchham Fm. – Khadir * possibly not | 445348 | 44.44 | 471.1 | 13837 | 19884 |
| HLS-082 | E | 43 | 3C | Pachchham Fm. – Juni Kuran | 476886 | 42.8 | 483 | 4875 | 5415 |
| HLS-083 | AB | 39 | 3+ | Pachchham Fm. – Khadir * possibly MSK | 487541 | 51.92 | 319.9 | 10566 | 2655 |
| HLS-084 | AB | 39 | 3+ | Unclear at this time * not Rohri Hills | 7965.74 | 81.28 | 38.8 | 5574 | 836 |
| HLS-085 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 488421 | 32.83 | 495.5 | 7686 | 3282 |
| HLS-086 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 514209 | 32.09 | 826.8 | 9036 | 4441 |
| HLS-087 | AB | 39 | 3C | Pachchham Fm. – Khadir quarry | 439958 | 217.85 | 338.9 | 10937 | 3114 |
| HLS-088 | AB | 39 | 3C | Pachchham Fm. – Juni Kuran | 458675 | 39.1 | 738.5 | 7308 | 3816 |
| HLS-089 | AB | 39 | 3C | Pachchham Fm. – Juni Kuran | 445316 | 41.13 | 788.2 | 12129 | 4833 |

| Sample# | Mound | Trench | Period | Probable geologic provenience | Ca | Ba | Sr | Fe | Mg |
|---|---|---|---|---|---|---|---|---|---|
| HLS-090 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 506587 | 32.06 | 761.5 | 8886 | 4521 |
| HLS-091 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 493961 | 38.02 | 664.1 | 8327 | 4275 |
| HLS-093 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 369045 | 45.71 | 415.7 | 5582 | 2555 |
| HLS-094 | AB | B | 3C+ | Pachchham Fm. – Khadir * possibly JK | 489640 | 54.93 | 452.5 | 6579 | 3084 |
| HLS-096 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 488596 | 80.25 | 514.1 | 10877 | 3686 |
| HLS-097 | AB | 39 | 3+ | Pachchham Fm. – Khadir * possibly JK | 476179 | 83.25 | 550 | 10686 | 4537 |
| HLS-098 | AB | B | 3C+ | Pachchham Fm. – Khadir * possibly JK | 475619 | 53.55 | 295.3 | 5037 | 3147 |
| HLS-099 | AB | B | 3C+ | Jaisalmer Fm. – Mool Sagar Khan | 469359 | 55.42 | 647.4 | 9283 | 4075 |
| HLS-100 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 477057 | 38.56 | 802 | 9060 | 4308 |
| HLS-101 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 438168 | 36.1 | 663.5 | 10465 | 4741 |
| HLS-102 | AB | 39 | 3+ | Pachchham Fm. – Juni Kuran | 443389 | 33.68 | 583.9 | 9103 | 4079 |
| HLS-103 | F | 43 | 3C | Pachchham Fm. – Juni Kuran | 452980 | 37.38 | 776.9 | 6697 | 3640 |
| HLS-104 | AB | B | 3C+ | Pachchham Fm. – Khadir<br>* possibly not | 305759 | 9.42 | 334.5 | 9873 | 11071 |
| HLS-105 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 318474 | 11.54 | 518.6 | 7435 | 4579 |
| HLS-106 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 317632 | 14.38 | 506.6 | 6883 | 4099 |
| HLS-107 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 322710 | 9.13 | 771.7 | 5249 | 3115 |
| HLS-108 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 316082 | 10.15 | 526.5 | 5629 | 2608 |
| HLS-109 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 301710 | 11.63 | 652.8 | 4694 | 2952 |
| HLS-110 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 244254 | 9.85 | 396.2 | 4157 | 2261 |
| HLS-111 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 297134 | 8.46 | 458.6 | 5285 | 2614 |
| HLS-112 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 322926 | 13.43 | 395.9 | 7221 | 3500 |
| HLS-113 | AB | B | 3C+ | Pachchham Fm. – Juni Kuran | 309994 | 52.55 | 575.7 | 5403 | 4153 |

# APPENDIX 11.6

# STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS FOR FIGURES IN CHAPTER 11 GENERATED USING CANONICAL DISCRIMINANT ANALYSIS

*Figure 11.24*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Sr/Ca) | 0.538854 | -0.263662 |
| Log(Ba/Ca) | -0.515918 | 0.632779 |
| Log(La/Ca) | 2.049668 | 1.390571 |
| Log(Ce/Ca) | -1.504577 | -0.910055 |

*Figure 11.25*

| | Function 1 | Function 2 |
|---|---|---|
| Log Al | -0.056874 | 0.749801 |
| Log Ca | -0.576539 | 0.134206 |
| Log Eu | 0.122040 | -0.401635 |
| Log Fe | -1.077745 | 0.440063 |
| Log La | 0.218032 | 0.290513 |
| Log Lu | 2.207798 | -1.296973 |
| Log Mg | -0.587172 | 1.065233 |
| Log Mn | -0.632225 | 0.721394 |
| Log Sr | 1.218172 | -0.332209 |
| Log V | -0.437484 | -0.647896 |

*Figure 11.27*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Sr/Ca) | 0.073614 | 0.464596 |
| Log(Ba/Ca) | 0.211263 | -1.461557 |
| Log(La/Ca) | 0.650717 | 0.909790 |
| Log(Ce/Ca) | 0.211846 | 0.326597 |

*Figures 11.30, 11.31, 11.32, 11.34, 11.37, & 11.39*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Ba/Ca) | -0.058470 | -0.342616 |
| Log(Sr/Ca) | 1.135848 | 0.240759 |
| Log(Mg/Ca) | -0.467101 | 0.446292 |
| Log(Fe/Ca) | -0.469716 | 0.689877 |

*Figure 11.36*

| | Function 1 |
|---|---|
| Log(Sr/Ca) | 0.844995 |
| Log(Mg/Ca) | 0.610469 |
| Log(Fe/Ca) | 0.420370 |
| Log(Ba/Ca) | -0.209630 |

*Figure 11.33*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Ba/Ca) | -0.364807 | 0.084021 |
| Log(Sr/Ca) | 0.907554 | -0.696177 |
| Log(Mg/Ca) | 0.098317 | 0.238141 |
| Log(Fe/Ca) | 0.188085 | 1.045765 |

*Figures 11.35 & 11.38*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Ba/Ca) | -0.438160 | -0.066719 |
| Log(Sr/Ca) | 1.000905 | -0.440645 |
| Log(Mg/Ca) | 0.139384 | 0.083884 |
| Log(Fe/Ca) | -0.054452 | 1.106942 |

*Figure 11.40*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Ba/Ca) | 0.319044 | 0.637698 |
| Log(Sr/Ca) | 0.255953 | 0.084343 |
| Log(Mg/Ca) | 0.192665 | -0.852032 |
| Log(Fe/Ca) | 0.703255 | 0.367320 |

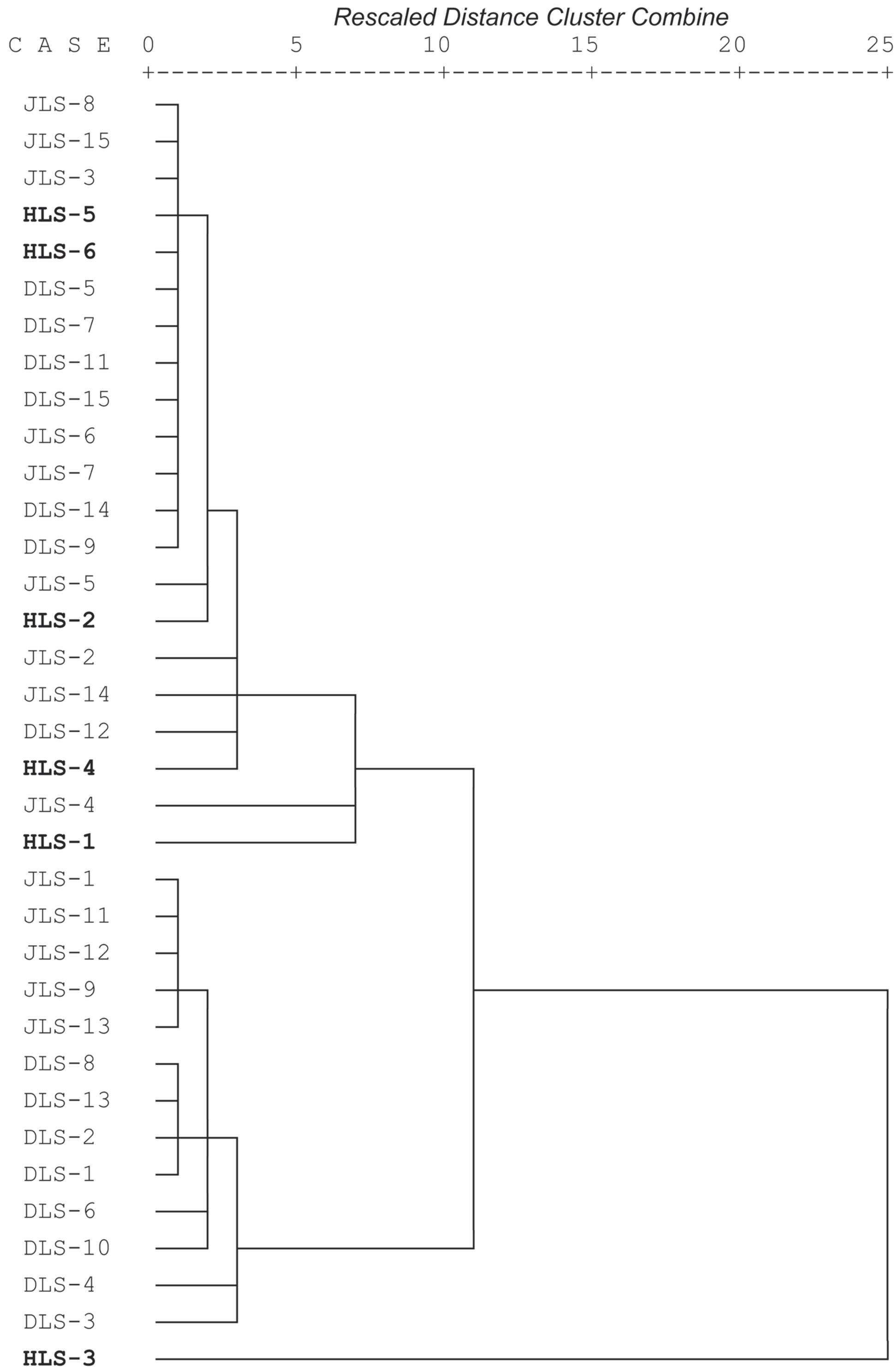
*Figure 11.41*

| | Function 1 | Function 2 |
|---|---|---|
| Log(Ba/Ca) | -0.031867 | -0.290917 |
| Log(Sr/Ca) | 1.136319 | 0.170960 |
| Log(Mg/Ca) | -0.422515 | 0.540320 |
| Log(Fe/Ca) | -0.443741 | 0.658560 |

# APPENDIX 11.7

## HIERARCHICAL CLUSTER ANALYSIS OF INITIAL LIMESTONE SAMPLES SET INAA DATA

Dendrogram generated using median clustering and Pearson correlation.



## APPENDIX 12.1

## PB ISOTOPE DATA FOR ORE SAMPLES FROM LEAD DEPOSITS IN INDIA, PAKISTAN AND OMAN

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Balochistan - Chagai (Koh-i-Sultan) | LARCH | ch1 | 2.4816 | 0.8439 | 15.604 |
| Balochistan - Chagai (Koh-i-Sultan) | LARCH | ch1.2 | 2.482 | 0.8433 | 15.635 |
| Balochistan - Chagai (Koh-i-Sultan) | LARCH | ch2 | 2.4756 | 0.8418 | 15.636 |
| Balochistan - Chagai (Koh-i-Sultan) | LARCH | ch2.2 | 2.4807 | 0.8417 | 15.639 |
| Balochistan - Chagai (Koh-i-Sultan) | LARCH | ch3 | 2.4817 | 0.8435 | 15.633 |
| Balochistan - Chagai (Koh-i-Sultan) | LARCH | ch3.2 | 2.4854 | 0.8412 | 15.64 |
| Balochistan - Chagai (Rekodiq) | LARCH | ch4 | 2.4856 | 0.8362 | 15.665 |
| Balochistan - Chagai (Rekodiq) | LARCH | ch4.2 | 2.4872 | 0.8366 | 15.655 |
| Balochistan - Chagai (Rekodiq) | LARCH | ch5 | 2.4833 | 0.8374 | 15.66 |
| Balochistan - Chagai (Rekodiq) | LARCH | ch5.2 | 2.4857 | 0.8375 | 15.713 |
| Balochistan - Chagai (Rekodiq) | LARCH | ch6 | 2.4847 | 0.8367 | 15.689 |
| Balochistan - Chagai (Rekodiq) | LARCH | ch6.2 | 2.4849 | 0.8355 | 15.634 |
| Balochistan - Khuzdar (Gunga) | LARCH | KHZ1 | 2.4578 | 0.845 | 15.614 |
| Balochistan - Khuzdar (Gunga) | LARCH | KHZ2 | 2.4499 | 0.8493 | 15.607 |
| Balochistan - Khuzdar (Gunga) | Siddiqui 1994: Table 7.4 | SGL-101 | 2.4693 | 0.8459 | 15.733 |
| Balochistan - Khuzdar (Gunga) | Siddiqui 1994: Table 7.4 | SGL-102 | 2.4697 | 0.8461 | 15.721 |
| Balochistan - Khuzdar (Gunga) | Siddiqui 1994: Table 7.4 | SGL-103 | 2.4656 | 0.8447 | 15.646 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | Bhutta 1992: Table 3 | AB258 | 2.463 | 0.85 | 15.703 |
| Balochistan - Las Bela - Kanrach Valley (Duddar) | Bhutta 1992: Table 3 | AB269 | 2.4667 | 0.8497 | 15.699 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | Bhutta 1992: Table 3 | AB295 | 2.4643 | 0.8489 | 15.694 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | LARCH | 3P-9 | 2.4619 | 0.8482 | 15.704 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | LARCH | 3P9B | 2.4612 | 0.8472 | 15.692 |
| Balochistan - Las Bela - Kanrach Valley (Bamph) | LARCH | hppb9 | 2.4588 | 0.8494 | 15.68 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | LARCH | KAN2 | 2.4526 | 0.8512 | 15.733 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | LARCH | KAN22 | 2.4631 | 0.8481 | 15.527 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | LARCH | KAN23 | 2.4573 | 0.8533 | 15.764 |
| Balochistan - Las Bela - Kanrach Valley (Kharrari) | LARCH | KAN24x2 | 2.4436 | 0.8544 | 15.662 |
| Balochistan - Las Bela - Kanrach Valley(Kharrari) | LARCH | KAN25 | 2.4501 | 0.8463 | 15.637 |
| Balochistan - Las Bela - Kanrach Valley (Bamph) | LARCH | KAN3 | 2.4542 | 0.8479 | 15.632 |
| Balochistan - Las Bela - Kanrach Valley (Bamph) | LARCH | KAN33 | 2.4593 | 0.8433 | 15.613 |
| Balochistan - Las Bela - Kanrach Valley (Bamph) | LARCH | KAN34 | 2.4585 | 0.8444 | 15.69 |

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Balochistan - Las Bela - Kanrach Valley (Bamph) | LARCH | KAN35 | 2.4718 | 0.8524 | 15.673 |
| Balochistan - Las Bela - Kanrach Valley (Duddar) | Siddiqui 1994: Table 7.4 | SGL-104 | 2.4702 | 0.8467 | 15.722 |
| Bihar - Amjhor | Balasubrahmanyan & Chandy 1976 | 11 | 2.4029 | 0.8915 | 15.61 |
| Bihar - Amjhor | Balasubrahmanyan & Chandy 1976 | 12 | 2.3959 | 0.896 | 15.76 |
| Bihar - Amjhor | Balasubrahmanyan & Chandy 1976 | 13 | 2.3931 | 0.8977 | 15.62 |
| Bihar - Hesatu-Pindara | Singh *et al.* 2001: Table 1 | TQ97-22 | 2.319 | 0.9564 | 15.494 |
| Bihar - Hesatu-Pindara | Singh *et al.* 2001: Table 1 | TQ97-23 | 2.3203 | 0.9573 | 15.564 |
| Bihar - Hesatu-Pindara | Singh *et al.* 2001: Table 1 | TQ97-24 | 2.3201 | 0.9571 | 15.537 |
| Bihar - Hesatu-Pindara | Singh *et al.* 2001: Table 1 | TQ97-25 | 2.3184 | 0.9563 | 15.498 |
| Bihar - Hesatu-Pindara | Singh *et al.* 2001: Table 1 | TQ97-26 | 2.3238 | 0.9574 | 15.567 |
| Gujarat - Ambadongar | Venkatasubramanian *et al.* 1982: Table I | n/a | 2.4685 | 0.8379 | 15.56 |
| Gujarat - Banejnes (Gir Forest) | LARCH | GIR-1 | 2.6496 | 0.7789 | 15.657 |
| Gujarat - Banejnes (Gir Forest) | LARCH | GIR-2 | 2.6628 | 0.779 | 15.704 |
| Gujarat - Banejnes (Gir Forest) | LARCH | GIR-3 | 2.6547 | 0.7795 | 15.711 |
| Gujarat - Banejnes (Gir Forest) | LARCH | GIR-4 | 2.6485 | 0.7803 | 15.717 |
| Gujarat - Banejnes (Gir Forest) | LARCH | GIR-5 | 2.6638 | 0.7789 | 15.727 |
| Gujarat - Khandia | LARCH | GK1 | 2.324 | 0.9508 | 15.691 |
| Gujarat - Khandia | LARCH | GK2 | 2.3237 | 0.9506 | 15.702 |
| Gujarat - Khandia | LARCH | GK3 | 2.327 | 0.95 | 15.692 |
| Gujarat - Khandia | LARCH | GK4 | 2.3241 | 0.9518 | 15.699 |
| Gujarat - Khandia | LARCH | GK5 | 2.326 | 0.9508 | 15.706 |
| Gujarat - Khandia | LARCH | GK6 | 2.3249 | 0.9515 | 15.71 |
| Gujarat/Rajasthan - Ambaji-Sendra - Ambaji | Deb *et al.* 1989: Table III | BH115/11A | 2.3876 | 0.9019 | 15.616 |
| Gujarat/Rajasthan - Ambaji-Sendra - Ambaji | Deb *et al.* 1989: Table III | BH115/7 | 2.3883 | 0.9026 | 15.613 |
| Gujarat/Rajasthan - Ambaji-Sendra - Ambaji | Deb *et al.* 1989: Table III | BH16/2 | 2.3869 | 0.9039 | 15.615 |
| Gujarat/Rajasthan - Ambaji-Sendra - Ambaji | Deb *et al.* 1989: Table III | BH89/9 | 2.3875 | 0.9041 | 15.615 |
| Gujarat/Rajasthan - Ambaji-Sendra - Ambaji | Deb *et al.* 1989: Table III | TQ85-29 | 2.3873 | 0.9034 | 15.616 |
| Gujarat/Rajasthan - Ambaji-Sendra - Ambaji | LARCH | Ambaji Pb | 2.3761 | 0.9127 | 15.833 |
| Gujarat/Rajasthan - Ambaji-Sendra - Amli Mal | Deb *et al.* 2001:Table 4 | TQ90-11 | 2.3928 | 0.907 | 15.612 |
| Gujarat/Rajasthan - Ambaji-Sendra - Amli Mal | Deb *et al.* 2001:Table 4 | TQ90-12 | 2.3929 | 0.907 | 15.608 |
| Gujarat/Rajasthan - Ambaji-Sendra - Basantgarh | Deb *et al.* 2001:Table 4 | TQ91-43 | 2.3719 | 0.9151 | 15.476 |
| Gujarat/Rajasthan - Ambaji-Sendra - Birantiya | Deb *et al.* 2001:Table 4 | TQ92-74 | 2.3952 | 0.8977 | 15.68 |
| Gujarat/Rajasthan - Ambaji-Sendra - Danva | Deb *et al.* 2001:Table 4 | TQ92-75 | 2.3617 | 0.927 | 15.351 |
| Gujarat/Rajasthan - Ambaji-Sendra - Deri | Deb *et al.* 1989: Table III | DR14/4 | 2.3867 | 0.9039 | 15.626 |
| Gujarat/Rajasthan - Ambaji-Sendra - Deri | Deb *et al.* 1989: Table III | DR9/14 | 2.3881 | 0.9035 | 15.623 |
| Gujarat/Rajasthan - Ambaji-Sendra - Deri | Deb *et al.* 1989: Table III | DR9/9 | 2.3871 | 0.9039 | 15.622 |

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Gujarat/Rajasthan - Ambaji-Sendra - Deri | Deb *et al*. 1989: Table III | Dupl. | 2.3888 | 0.9035 | 15.628 |
| Gujarat/Rajasthan - Ambaji-Sendra - Kumbariya | Deb *et al*. 2001:Table 4 | 4 | 2.3853 | 0.9019 | 15.656 |
| Haryana - Tosham | Deb *et al*. 2001:Table 4 | TQ89-8 | 2.4165 | 0.8833 | 15.727 |
| Himachal Pradesh - Amba Kala | LARCH | AKHP1 | 2.4409 | 0.8498 | 15.732 |
| Himachal Pradesh - Amba Kala | LARCH | AKHP2 | 2.4381 | 0.8542 | 15.716 |
| Himachal Pradesh - Amba Kala | LARCH | AKHP3 | 2.4388 | 0.8496 | 15.754 |
| Himachal Pradesh - Amba Kala | LARCH | AKHP4 | 2.4385 | 0.8518 | 15.728 |
| Himachal Pradesh - Amba Kala | LARCH | AKHP5 | 2.4407 | 0.8495 | 15.748 |
| Himachal Pradesh - Panuh | LARCH | HPP-1 | 2.4526 | 0.8416 | 15.872 |
| Himachal Pradesh - Panuh | LARCH | HPP-1B | 2.4513 | 0.8416 | 15.866 |
| Himachal Pradesh - Panuh | LARCH | HPP-2 | 2.4522 | 0.8435 | 15.939 |
| Himachal Pradesh - Panuh | LARCH | HPP-2C | 2.4509 | 0.8427 | 16.021 |
| Himachal Pradesh - Panuh | LARCH | HPP-3 | 2.4588 | 0.8431 | 15.95 |
| Himachal Pradesh - Panuh | LARCH | HPP-3B | 2.4529 | 0.8408 | 15.885 |
| Himachal Pradesh - Panuh | LARCH | HPP-4 | 2.4535 | 0.8446 | 15.934 |
| Himachal Pradesh - Panuh | LARCH | HPP-4B | 2.4559 | 0.8419 | 15.911 |
| Himachal Pradesh - Panuh | LARCH | HPP-5 | 2.4531 | 0.8448 | 15.944 |
| Himachal Pradesh - Panuh | LARCH | HPP-5B | 2.4606 | 0.8419 | 15.911 |
| Himachal Pradesh - Tal | LARCH | HPT-1 | 2.4538 | 0.8329 | 16.133 |
| Himachal Pradesh - Tal | LARCH | HPT-2 | 2.4597 | 0.8308 | 16.072 |
| Himachal Pradesh - Tal | LARCH | HPT-3 | 2.4608 | 0.8306 | 16.02 |
| Himachal Pradesh - Tal | LARCH | HPT-4 | 2.4525 | 0.8318 | 16.087 |
| Himachal Pradesh - Tal | LARCH | HPT-5 | 2.4538 | 0.8314 | 16.059 |
| Himachal Pradesh - Uchich | LARCH | HPU-1 | 2.5775 | 0.7102 | 15.832 |
| Himachal Pradesh - Uchich | LARCH | HPU-2 | 2.572 | 0.7119 | 15.499 |
| Himachal Pradesh - Uchich | LARCH | HPU-3 | 2.5665 | 0.7081 | 15.501 |
| Himachal Pradesh - Uchich | LARCH | HPU-5 | 2.5758 | 0.7135 | 16.145 |
| Himachal Pradesh - Uchich | LARCH | HPU-4 | 2.5828 | 0.7059 | 15.299 |
| Jammu & Kashmir - Buniyar | LARCH | RB2 | 2.3525 | 0.9066 | 15.473 |
| Jammu & Kashmir - Buniyar | LARCH | rb2-2 | 2.3346 | 0.9115 | 15.381 |
| Jammu & Kashmir - Buniyar | LARCH | RB3 | 2.3605 | 0.9093 | 15.538 |
| Jammu & Kashmir - Buniyar | LARCH | RB3-2 | 2.3601 | 0.906 | 15.557 |
| Jammu & Kashmir - Buniyar | LARCH | RB3B | 2.3513 | 0.908 | 15.592 |
| Jammu & Kashmir - Buniyar | LARCH | RB4 | 2.3434 | 0.9084 | 15.425 |
| Jammu & Kashmir - Buniyar | LARCH | RB4-2 | 2.3554 | 0.9101 | 15.575 |
| Jammu & Kashmir - Riasi (Kheri Kot) | LARCH | KK1 | 2.3589 | 0.9108 | 15.6 |
| Jammu & Kashmir - Riasi (Kheri Kot) | LARCH | KK2 | 2.3572 | 0.9127 | 15.602 |
| Jammu & Kashmir - Riasi (Kheri Kot) | LARCH | KK3 | 2.358 | 0.9112 | 15.599 |
| Jammu & Kashmir - Riasi (Kheri Kot) | LARCH | KK4 | 2.3586 | 0.9109 | 15.576 |
| Jammu & Kashmir - Riasi (Kheri Kot) | LARCH | KK5 | 2.3583 | 0.911 | 15.603 |

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Jammu & Kashmir - Riasi (Kheri Kot) | LARCH | KK6 | 2.3571 | 0.9115 | 15.599 |
| Jammu & Kashmir - Riasi (Darabi) | LARCH | RD1 | 2.3472 | 0.9282 | 15.66 |
| Jammu & Kashmir - Riasi (Darabi) | LARCH | RD1A | 2.339 | 0.9278 | 15.983 |
| Jammu & Kashmir - Riasi (Darabi) | LARCH | RD2 | 2.3528 | 0.9164 | 16.78 |
| Jammu & Kashmir - Riasi (Darabi) | LARCH | RD3 | 2.3591 | 0.9169 | 15.824 |
| Jammu & Kashmir - Riasi (Darabi) | LARCH | RD4 | 2.3578 | 0.9172 | 16.168 |
| Jammu & Kashmir - Riasi (Sersendu) | Raha *et al*. 1978: Table II | 0.25 | 2.3686 | 0.9171 | 15.6 |
| Jammu & Kashmir - Riasi (Sersendu) | Raha *et al.* 1978: Table II | I/3 | 2.3697 | 0.9138 | 15.47 |
| Jammu & Kashmir - Riasi (Sersendu) | Raha *et al.* 1978: Table II | II/2 | 2.3631 | 0.9105 | 15.56 |
| Jammu & Kashmir - Riasi (Sersendu) | Raha *et al.* 1978: Table II | II/I | 2.3688 | 0.9178 | 15.51 |
| NWFP - Besham (Lahor) | Shah *et al*. 1992: Table 1 | n/a | 2.2878 | 1.0193 | 15.085 |
| NWFP - Besham (Lahor) | Shah *et al*. 1992: Table 1 | n/a | 2.2883 | 1.0172 | 15.097 |
| NWFP - Besham (Lahor) | Shah *et al*. 1992: Table 1 | n/a | 2.2892 | 1.0192 | 15.106 |
| NWFP - Besham (Pazang) | Shah *et al*. 1992: Table 1 | n/a | 2.2864 | 1.0131 | 15.116 |
| NWFP - Besham (Pazang) | Shah *et al*. 1992: Table 1 | n/a | 2.2865 | 1.017 | 15.096 |
| NWFP - Chitral | Tahirkheli *et al*. 1997: Table 1 | Tz203 | 2.493 | 0.8361 | 15.66 |
| NWFP - Chitral | Tahirkheli *et al*. 1997: Table 1 | Tz5 | 2.4971 | 0.8371 | 15.73 |
| NWFP - Chitral | Tahirkheli *et al*. 1997: Table 1 | Tz8 | 2.4962 | 0.8349 | 15.68 |
| Oman - Qumayrah | Calvez and Lescuyer 1991: Table 1 | JL90-35 | 2.481 | 0.8376 | 15.689 |
| Oman - Ibra (Semail Ophiolite) | Chen and Pallister 1981: Table 1 | OMG-15 | 2.4766 | 0.8408 | 15.719 |
| Oman - Wadi Mayh | Calvez and Lescuyer 1991: Table 1 | C533 | 2.4535 | 0.8624 | 15.734 |
| Oman - Wadi Nujum | Keck Isotope Laboratry | OWN-1 | 2.4795 | 0.8378 | 15.654 |
| Oman - Wadi Nujum | Keck Isotope Laboratry | OWN-2 | 2.4792 | 0.8385 | 15.655 |
| Oman - Wadi Nujum | Keck Isotope Laboratry | OWN-3 | 2.4793 | 0.838 | 15.643 |
| Oman - Wadi Nujum | Keck Isotope Laboratry | OWN-4 | 2.4795 | 0.8377 | 15.655 |
| Rajasthan - Khera Mawal | Keck Isotope Laboratry | RKM-1 | 2.4623 | 0.8606 | 15.774 |
| Rajasthan - Khera Mawal | Keck Isotope Laboratry | RKM-2 | 2.4619 | 0.8608 | 15.774 |
| Rajasthan - Khera Mawal | Deb *et al*. 2001:Table 4 | TQ95-45 | 2.4641 | 0.8609 | 15.778 |
| Rajasthan - Lohakhan | LARCH | point119 | 2.3106 | 0.9544 | 15.65 |
| Rajasthan - Punagarh Hill | Deb *et al*. 2001:Table 4 | TQ96-3 | 2.4031 | 0.8851 | 15.787 |
| Rajasthan - Punagarh Hill | Deb *et al*. 2001:Table 4 | TQ96-4 | 2.3942 | 0.8863 | 15.78 |
| Rajasthan - Rajpura-Dariba | Balasubrahmanyan & Chandy 1976 | 5 | 2.305 | 0.961 | 15.51 |
| Rajasthan - Rajpura-Dariba | Balasubrahmanyan & Chandy 1976 | 6 | 2.2688 | 0.9635 | 15.59 |
| Rajasthan - Rajpura-Dariba | Balasubrahmanyan & Chandy 1976 | 7 | 2.3059 | 0.9682 | 15.53 |
| Rajasthan - Rajpura-Dariba | Balasubrahmanyan & Chandy 1976 | 8 | 2.3155 | 0.9706 | 15.53 |
| Rajasthan - Rajpura-Dariba | Balasubrahmanyan & Chandy 1976 | 9 | 2.2995 | 0.9621 | 15.49 |
| Rajasthan - Rajpura-Dariba | Balasubrahmanyan & Chandy 1976 | 10 | 2.2987 | 0.9592 | 15.5 |
| Rajasthan - Rajpura-Dariba | Deb *et al*. 1989: Table III | Dupl. | 2.3102 | 0.966 | 15.486 |
| Rajasthan - Rajpura-Dariba | Deb *et al*. 1989: Table III | Dupl. | 2.311 | 0.966 | 15.492 |

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | Dupl. | 2.3112 | 0.9657 | 15.494 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/208 | 2.3116 | 0.966 | 15.49 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/224 | 2.3114 | 0.9658 | 15.488 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/231 | 2.3097 | 0.9658 | 15.488 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/247 | 2.3109 | 0.966 | 15.485 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/263 | 2.3109 | 0.966 | 15.494 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/27 | 2.3115 | 0.9655 | 15.488 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/28 | 2.3099 | 0.9659 | 15.499 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/305 | 2.3109 | 0.9658 | 15.49 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/52 | 2.3109 | 0.9658 | 15.489 |
| Rajasthan - Rajpura-Dariba | Deb *et al.* 1989: Table III | RD400/8 | 2.311 | 0.9662 | 15.492 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | Dupl. | 2.3106 | 0.9657 | 15.503 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | Dupl. | 2.311 | 0.9655 | 15.506 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | Dupl. | 2.3111 | 0.9657 | 15.505 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | Dupl. | 2.3112 | 0.9659 | 15.507 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | Dupl. | 2.3114 | 0.9659 | 15.506 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | Dupl. | 2.3124 | 0.9658 | 15.498 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | RA/OD/5 | 2.3111 | 0.9657 | 15.499 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | RA/OD/7 | 2.3104 | 0.9658 | 15.495 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | RA84/A | 2.3117 | 0.9657 | 15.507 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | RA84/B | 2.3109 | 0.9656 | 15.509 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | RA84/C | 2.3117 | 0.9658 | 15.504 |
| Rajasthan - Rampura-Agucha | Deb *et al.* 1989: Table III | RD400/8 | 2.312 | 0.9658 | 15.512 |
| Rajasthan - Saladipura | Deb *et al.* 1989: Table III | Dupl. | 2.3118 | 0.9642 | 15.492 |
| Rajasthan - Saladipura | Deb *et al.* 1989: Table III | TQ 85-24 | 2.3126 | 0.9642 | 15.498 |
| Rajasthan - Sawai Madhopur | LARCH | RSM-1 | 2.3187 | 0.9464 | 15.805 |
| Rajasthan - Sawai Madhopur | LARCH | RSM-2 | 2.3114 | 0.9494 | 15.788 |
| Rajasthan - Sawai Madhopur | LARCH | RSM-3 | 2.314 | 0.9502 | 15.802 |
| Rajasthan - Sawai Madhopur | LARCH | RSM-4 | 2.3227 | 0.9494 | 15.731 |
| Rajasthan - Sawai Madhopur | LARCH | RSM-5 | 2.3128 | 0.9524 | 15.831 |
| Rajasthan - Zawar | Balasubrahmanyan & Chandy 1976 | 1 | 2.3195 | 0.952 | 15.68 |
| Rajasthan - Zawar | Balasubrahmanyan & Chandy 1976 | 2 | 2.3152 | 0.9462 | 15.64 |
| Rajasthan - Zawar | Balasubrahmanyan & Chandy 1976 | 3 | 2.3227 | 0.9456 | 15.65 |
| Rajasthan - Zawar | Balasubrahmanyan & Chandy 1976 | 4 | 2.3179 | 0.9512 | 15.6 |
| Rajasthan - Zawar Mines | LARCH | Zawar Pb | 2.3227 | 0.9479 | 15.674 |
| Rajasthan - Zawar-Baroi | Deb *et al.* 1989: Table III | BM4 | 2.3234 | 0.9483 | 15.706 |
| Rajasthan - Zawar-Baroi | Deb *et al.* 1989: Table III | BM6 | 2.3253 | 0.9479 | 15.723 |
| Rajasthan - Zawar-Baroi | Deb *et al.* 1989: Table III | BM7 | 2.3217 | 0.9488 | 15.683 |
| Rajasthan - Zawar-Baroi | Deb *et al.* 1989: Table III | Dupl. | 2.3232 | 0.9478 | 15.721 |
| Rajasthan - Zawarmala | Deb *et al.* 1989: Table III | Dupl. | 2.3237 | 0.9477 | 15.725 |

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Rajasthan - Zawarmala | Deb *et al*. 1989: Table III | Dupl. | 2.3241 | 0.9467 | 15.698 |
| Rajasthan - Zawarmala | Deb *et al*. 1989: Table III | Dupl. | 2.3248 | 0.9471 | 15.708 |
| Rajasthan - Zawarmala | Deb *et al*. 1989: Table III | ZM14 | 2.3249 | 0.9469 | 15.708 |
| Rajasthan - Zawarmala | Deb *et al*. 1989: Table III | ZM22 | 2.3225 | 0.9476 | 15.694 |
| Rajasthan - Zawarmala | Deb *et al*. 1989: Table III | ZM27 | 2.3245 | 0.9489 | 15.694 |
| Rajasthan - Zawarmala | Deb *et al*. 1989: Table III | ZM5 | 2.3233 | 0.9479 | 15.722 |
| Rajasthan - Zawar-Mochia | Deb *et al*. 1989: Table III | BL5 | 2.3215 | 0.9499 | 15.666 |
| Rajasthan - Zawar-Mochia | Deb *et al*. 1989: Table III | BL9 | 2.3215 | 0.95 | 15.66 |
| Rajasthan - Zawar-Mochia | Deb *et al*. 1989: Table III | Dupl. | 2.3209 | 0.9499 | 15.657 |
| Rajasthan - Zawar-Mochia | Deb *et al*. 1989: Table III | Dupl. | 2.3221 | 0.9503 | 15.67 |
| Rajasthan - Zawar-Mochia | Deb *et al*. 1989: Table III | ZMC15 | 2.3219 | 0.9502 | 15.663 |
| Rajasthan - Zawar-Mochia | Deb *et al*. 1989: Table III | ZMC2 | 2.3222 | 0.9502 | 15.672 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 1 | 2.3053 | 0.9415 | 15.721 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 2 | 2.3057 | 0.9408 | 15.736 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 3 | 2.3052 | 0.9408 | 15.731 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 4 | 2.3077 | 0.9418 | 15.77 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 5 | 2.3042 | 0.9402 | 15.718 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 6 | 2.3055 | 0.9408 | 15.738 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 7 | 2.3043 | 0.9405 | 15.714 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 8 | 2.3074 | 0.9421 | 15.758 |
| South India - Andhra Pradesh - Agnigundala | Srinivasa 1999: Table 2 | 9 | 2.3061 | 0.9419 | 15.744 |
| South India - Andhra Pradesh - Chelima | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.323 | 0.9466 | 15.42 |
| South India - Karnataka - Arothikoppal | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.3234 | 0.95 | 15.4 |
| South India - Karnataka - G.R. Halli | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.2724 | 1.0903 | 14.61 |
| South India - Karnataka - Kolar | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.268 | 1.0475 | 15 |
| South India - Karnataka - Kunchiganahalu | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.3008 | 1.1392 | 13.83 |
| South India - Karnataka - Kurubaramaradikere | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.2855 | 1.0813 | 14.5 |
| South India - Karnataka -Bukkambudhi | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.3156 | 1.1272 | 13.91 |
| South India - Tamil Nadu - Kurichi | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.3497 | 0.9318 | 15.44 |
| South India - Tamil Nadu - Mamandur | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.2692 | 1.05 | 15.12 |
| South India - Tamil Nadu - Metri | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.3491 | 0.9296 | 15.44 |
| South India - Andhra Pradesh - Chelima | Venkatasubramanian *et al*. 1982: Table I | n/a | 2.323 | 0.9466 | 15.42 |
| Sikkim - Rangpo | Sarkar *et al*. 2000: Table 1 | MAHW/17/B/7 | 2.303 | 0.974 | 15.41 |
| Sikkim - Rangpo | Sarkar *et al*. 2000: Table 1 | MAHW/17/R/6 | 2.2805 | 0.9736 | 15.457 |
| Sikkim - Rangpo | Sarkar *et al*. 2000: Table 1 | NAB-3/P/5 | 2.3009 | 0.9735 | 15.386 |
| Sikkim - Rangpo | Sarkar *et al*. 2000: Table 1 | NAFW/2/R/8 | 2.3012 | 0.9736 | 15.4 |
| Uttaranchal - Askot | LARCH | AS28B | 2.297 | 0.97 | 15.457 |

| region - deposit | reference | sample | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Uttaranchal - Askot | LARCH | RR-84-B2 | 2.288 | 0.9718 | 15.329 |
| Uttaranchal - Askot | LARCH | RR85 | 2.3001 | 0.9727 | 15.966 |
| Uttaranchal - Bageshwar | Sarkar *et al*. 2000: Table 1 | B6-1 | 2.3121 | 0.9576 | 15.551 |
| Uttaranchal - Bageshwar | Sarkar *et al*. 2000: Table 1 | B6-2 | 2.3176 | 0.9471 | 15.555 |
| Uttaranchal - Bageshwar | Sarkar *et al*. 2000: Table 1 | B6-3 | 2.3127 | 0.9572 | 15.541 |
| Uttaranchal - Khansue | LARCH | GK74/1 | 2.372 | 0.8513 | 15.729 |
| Uttaranchal - Khansue | LARCH | GK74/3 | 2.3803 | 0.854 | 15.743 |
| West Bengal - Gorubathan | Sarkar *et al*. 2000: Table 1 | D2/6/4 | 2.2955 | 0.9726 | 15.511 |
| West Bengal - Gorubathan | Sarkar *et al*. 2000: Table 1 | K5/6/1 | 2.3011 | 0.9729 | 15.428 |
| West Bengal - Gorubathan | Sarkar *et al*. 2000: Table 1 | S/31/6/3 | 2.3028 | 0.9741 | 15.42 |

# APPENDIX 12.2

# CONTEXT AND PB ISOTOPE DATA FOR 19 ARCHAEOLOGICAL LEAD ORE FRAGMENTS FROM HARAPPA

| artifact number | material | mound-trench | context | 208/207 | 207/206 | 207/204 | probable geologic provenience |
|---|---|---|---|---|---|---|---|
| H93/4001-1 | galena | ET - 10 | surface | 2.3666 | 0.91 | 15.616 | Jammu and Kashmir |
| H96/7512-10 | galena | AB - 39 | Period 1 | 2.3432 | 0.91 | 15.578 | Jammu and Kashmir |
| H89/1038-21 | galena | AB / E - 53 | disturbed | 2.3577 | 0.9086 | 15.641 | Jammu and Kashmir |
| H90/3011-147 | galena | E - survey | surface | 2.4411 | 0.8584 | 15.759 | unclear at this time |
| H90/3011-148 | galena | E - survey | surface | 2.4366 | 0.8613 | 15.763 | unclear at this time |
| H99/7649-31 | galena | F- 41 | Period 3C | 2.3556 | 0.9107 | 15.599 | Jammu and Kashmir |
| H98/8158-62 | galena | E - 11 | Period 3C | 2.3543 | 0.9116 | 15.576 | Jammu and Kashmir |
| H2000/2102-143 | galena | E - 54 | disturbed | 2.3548 | 0.9141 | 15.603 | Jammu and Kashmir |
| H2000/2101-1726 | galena | E - 54 | disturbed | 2.3577 | 0.9055 | 15.628 | Jammu and Kashmir |
| H2000/2226-111 | galena | E - 54 | disturbed | 2.3545 | 0.9099 | 15.626 | Jammu and Kashmir |
| H2000/9999-73 | galena | E - survey | surface | 2.3562 | 0.9115 | 15.579 | Jammu and Kashmir |
| H99/8857-1 | cerussite-anglesite | E - 11 | disturbed | 2.4721 | 0.8469 | 15.701 | southern Balochistan |
| H99/8755-152 | cerussite-anglesite | F - 43 | Period 3C | 2.4608 | 0.8474 | 15.738 | southern Balochistan |
| H2000/2139-141 | cerussite-anglesite | E - 54 | disturbed | 2.4731 | 0.8455 | 15.635 | southern Balochistan |
| H2000/2342-40 | massicot | E - 54 | disturbed | 2.4351 | 0.8586 | 15.815 | unclear at this time |
| H88/715-15 | massicot | E - 52 | Period 3C | 2.4677 | 0.8466 | 15.704 | southern Balochistan |
| H90/3030-1 | massicot | E - 1 | disturbed | 2.4197 | 0.8673 | 15.758 | unclear at this time |
| H2001/9091-1 | massicot | E - 11 | Period 3C | 2.4443 | 0.8651 | 15.639 | unclear at this time |
| H90/3193-6 | massicot | E - 58 | Period 3C | 2.4629 | 0.8443 | 15.636 | southern Balochistan |

# APPENDIX 12.3

# PB ISOTOPE DATA FOR LEAD ARTIFACTS, SLAGS, LUMPS AND RESIDUES FROM HARAPPA

| artifact number | material | mound-trench | context | 208/207 | 207/206 | 207/204 | probable geologic provenience |
|---|---|---|---|---|---|---|---|
| H93/3506-43 | lead rod | E - 1 | disturbed | 2.4368 | 0.8689 | 15.797 | Unclear at this time |
| H88/197-1 | wulfenite rod | cemetery | Period 3B | 2.3479 | 0.9093 | 15.585 | Jammu and Kashmir |
| H2000/2174-321 | inscribed lead bar | E - 54 | surface | 2.4631 | 0.8486 | 15.634 | southern Balochistan |
| H94/4891-214 | lead piece | ET - 27 | Period 3C | 2.4497 | 0.8653 | 15.72 | unclear at this time (Oman?) |
| H2000/2102-1555 | lead bar | E - 54 | disturbed | 2.449 | 0.8644 | 15.606 | unclear at this time (Oman?) |
| H2000/2226-50 | lead bar/chisel | E - 54 | disturbed | 2.4505 | 0.846 | 15.667 | southern Balochistan |
| H88/446-04 | lead repair plug in shell ladle | cemetery | Period 3B | 2.4379 | 0.8662 | 15.69 | Unclear at this time |
| H93/3892-69 | porous slag with lead inclusions | E - 8 | surface | 2.4654 | 0.8433 | 15.701 | southern Balochistan |
| H93/3563-13 | slag with yellow encrustation | E - 4 | Period 3C | 2.4555 | 0.8634 | 15.679 | Unclear at this time |
| H95/6006-1 | melted lead lump | north of F | surface | 2.4689 | 0.8436 | 15.731 | southern Balochistan |
| H2001/11701-6 | melted lead lump | E - 11 | surface | 2.3575 | 0.914 | 15.548 | Jammu and Kashmir |
| H93/3511-37 | slag w/ green and yellow encrustation | E - 1 | disturbed | 2.4136 | 0.8738 | 15.514 | Unclear at this time |
| H93/3804-5 | slag w/ green and yellow encrustation | E - 5 | disturbed | 2.4573 | 0.8556 | 15.597 | southern Balochistan |
| H87/539-80 | lead residue inside "surma" bottle | AB - 50 | Period 3C | 2.3558 | 0.9074 | 15.806 | Jammu and Kashmir |
| H98/8158-26 | lead residue inside "surma" bottle | E - 11 | Period 3C | 2.369 | 0.9115 | 15.753 | Jammu and Kashmir |
| [HM 9697 V3906] | lead residue inside "surma" bottle | Unknown | Unknown | 2.3472 | 0.9114 | 15.799 | Jammu and Kashmir |

# APPENDIX 12.4

# PB ISOTOPE DATA FOR LEAD ARTIFACTS FROM SHAHR-I-SOKHTA, MUNDIGAK, MEHRGARH, NAUSHARO, GOLA DHORO AND MOHENJO-DARO

| site | analysis # / artifact number | artifact type | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| Shahr-i-Sokhta | SiS151 | galena fragment | 2.4704 | 0.8497 | 15.606 |
| Shahr-i-Sokhta | SiS11390 | galena fragment | 2.4747 | 0.8412 | 15.599 |
| Mundigak | MGK-1 / MGB 36 CLXXXVII (3) | galena fragment | 2.4727 | 0.8510 | 15.714 |
| Mundigak | MGK-2 / MG G91 (3) | galena fragment | 2.4678 | 0.8517 | 15.704 |
| Mundigak | MGK-3 / no # | galena fragment | 2.4792 | 0.8488 | 15.665 |
| Mundigak | MGK-4 / MGA XXXII *a* | galena fragment | 2.4629 | 0.8488 | 15.630 |
| Mundigak | MGK-5 / MGA XXXII *b* | galena fragment | 2.4609 | 0.8488 | 15.661 |
| Mundigak | MGK-6 / MGA XXXII *c* | galena fragment | 2.4653 | 0.8480 | 15.596 |
| Mundigak | MGK-7 / no # | galena fragment | 2.4793 | 0.8504 | 15.664 |
| Mundigak | MGK-8 / no # | galena fragment | 2.4691 | 0.8501 | 15.659 |
| Mundigak | MGK-9 / no # | galena fragment | 2.4763 | 0.8497 | 15.663 |
| Mundigak | MGK-10 / MG J12 Tepe A | lead sheet | 2.4658 | 0.8412 | 15.562 |
| Mundigak | MGK-11 / MG J12 Tepe A | lead sheet | 2.4744 | 0.8390 | 15.611 |
| Mundigak | MGK-12 / MG 6.1 | lead ring | 2.4774 | 0.8459 | 15.643 |
| Mundigak | MGK-14 / no # | galena fragment | 2.4811 | 0.8503 | 15.681 |
| Mehrgarh | MR-L1 / MR4 F6B (2) – large ( MR 78 04 11 24) | galena fragment | 2.4641 | 0.8467 | 15.755 |
| Mehrgarh | MR-L2 / MR4 F6B (2) – small ( MR 78 04 11 25) | galena fragment | 2.4710 | 0.8482 | 15.767 |
| Mehrgarh | MR-L3 / MR4 F6B (2) *c* ( MR 78 04 11 26) | galena fragment | 2.4585 | 0.8485 | 15.749 |
| Mehrgarh | MR-L4 / MR79.04.73.59 | galena fragment | 2.4657 | 0.8469 | 15.708 |
| Mehrgarh | MR-L5 / L31121 | galena fragment | 2.4698 | 0.8458 | 15.702 |
| Mehrgarh | MR-L6 / L31122 | galena fragment | 2.4800 | 0.8446 | 15.708 |
| Mehrgarh | MR-L7 / MR4 F6B (1) 78 (MR 78 04 10 31) | galena fragment | 2.4759 | 0.8442 | 15.681 |
| Gola Dhoro | BRS-5930 | lead lump | 2.4669 | 0.8471 | 15.674 |
| Nausharo | NS-L1 / NS-9111 6303 loc. XII | lead ring | 2.4719 | 0.8447 | 15.697 |
| Mohenjo-daro | MD-S / no # | "surma" bottle residue | 2.4316 | 0.8660 | 15.516 |
| Mohenjo-daro | MD-L1 / MD-88 711 | galena fragment | 2.4668 | 0.8437 | 15.672 |

# APPENDIX 12.5

# PB ISOTOPE DATA FOR SILVER ARTIFACTS FROM ALLAHDINO, MOHENJO-DARO, MUNDIGAK, GOLA DHORO AND NAGWADA

| Site | analysis number | accession number | artifact type | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|---|
| Mundigak | MGK-13 | MGB 40 CXCIX | ring | 2.4938 | 0.8353 | 15.629 |
| Nagwada | NGW-1 | n/a | ring fragment | 2.4677 | 0.8522 | 15.685 |
| Gola Dhoro | BSR-7053 | n/a | ring | 2.4797 | 0.8397 | 15.696 |
| Mohenjo-daro | NM-1 | 50.47, S. no 12 | bangle | 2.4462 | 0.8636 | 15.624 |
| Mohenjo-daro | NM-1 | NMP#8 | bead | 2.4468 | 0.8652 | 15.577 |
| Mohenjo-daro | NM-1 | NMP#8 | bead | 2.4437 | 0.8629 | 15.538 |
| Mohenjo-daro | NM-1 | NMP#8 | bead | 2.4420 | 0.8672 | 15.548 |
| Mohenjo-daro | NM-1 | NMP#50.22/6 | button or nose stud | 2.4304 | 0.8701 | 15.473 |
| Allahdino | AD-1 | 2070 A | large flat bead with triple hole | 2.4695 | 0.8455 | 15.666 |
| Allahdino | AD-2 | 2070 B | large flat bead with triple hole | 2.4651 | 0.8494 | 15.583 |
| Allahdino | AD-3 | 2101 A | small bead | 2.4647 | 0.8520 | 15.343 |
| Allahdino | AD-4 | 2101 B | small bead | 2.4608 | 0.8500 | 15.474 |
| Allahdino | AD-5 | 2101 C | bead | 2.4429 | 0.8539 | 15.487 |
| Allahdino | AD-6 | 2101 E | bead | 2.4478 | 0.8569 | 15.623 |
| Allahdino | AD-7 | 2101 F | bead | 2.4607 | 0.8511 | 15.604 |
| Allahdino | AD-8 | 2111 A | toe ring | 2.4709 | 0.8466 | 15.674 |
| Allahdino | AD-9 | 2111 B | bead | 2.4409 | 0.8705 | 15.747 |
| Allahdino | AD-10 | 2111 B | lump of twisted bands | 2.4561 | 0.8481 | 15.655 |

# APPENDIX 12.6

# PB ISOTOPE DATA FOR THE ARGENTIFEROUS GALENA DEPOSIT AT NAKHLAK, IRAN

(extrapolated from Stos-Gale 2001: Table 4.1)

| Sample number | Material | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|
| Pb-835 | Litharge | 2.4738 | 0.84509 | 15.690 |
| Pb-833 | Pb slag/litharge | 2.4715 | 0.84479 | 15.647 |
| Pb-832 | Cerussite | 2.4743 | 0.84480 | 15.645 |
| Pb-834 | galena | 2.4710 | 0.84525 | 15.670 |
| PI 1b | Pb slag | 2.4712 | 0.84468 | 15.654 |
| PI 2 | Pb slag | 2.4706 | 0.84466 | 15.651 |
| PI 1a | Pb slag | 2.4710 | 0.84463 | 15.655 |

# APPENDIX 12.7

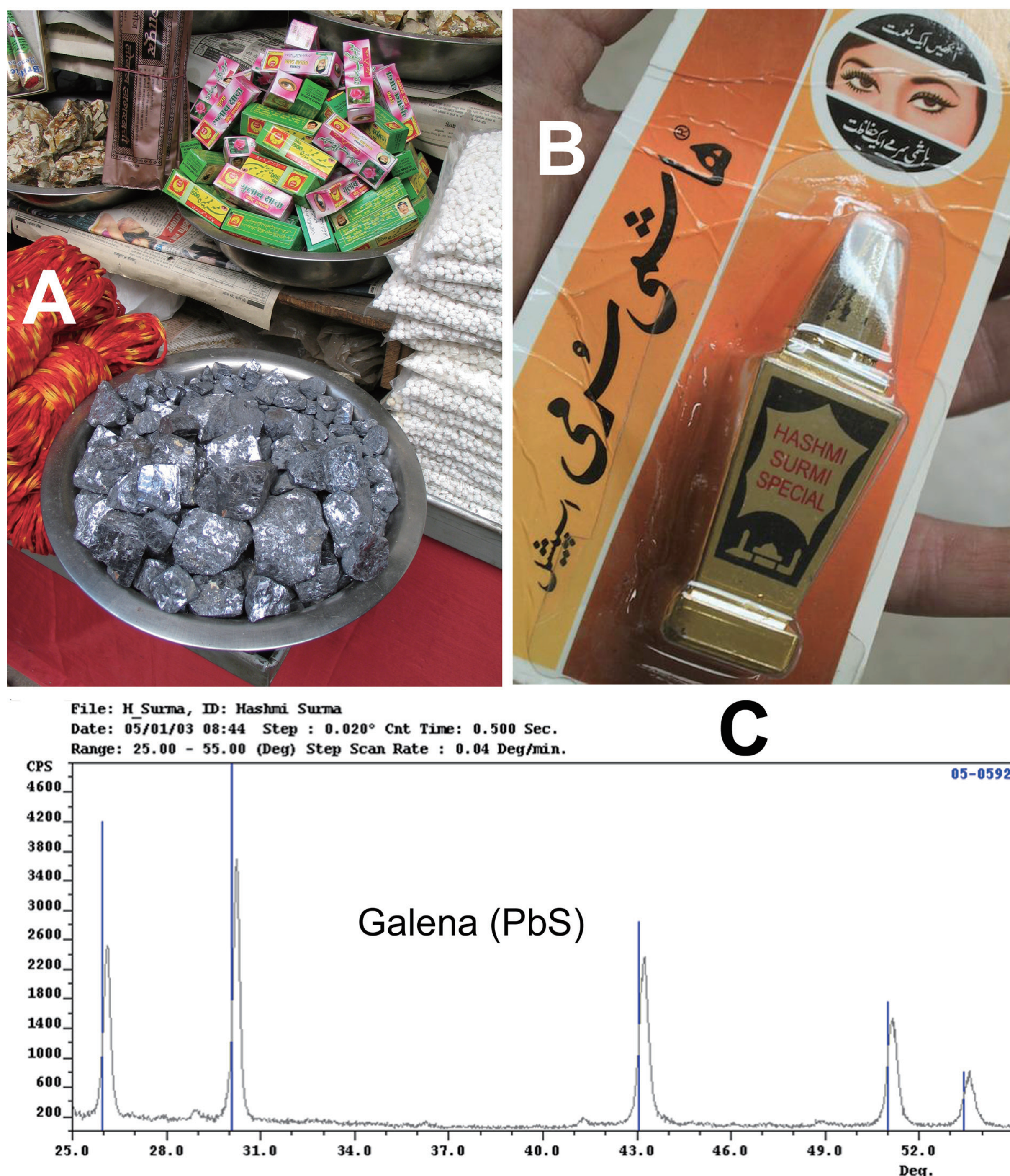
## XRD AND PB ISOTOPE ANALYSES OF MODERN LEAD OBJECTS AND SUBSTANCES

During the course of my research on the acquisition and use of lead in ancient northwestern South Asia, I frequently came across of modern lead objects and lead substances that, for informational and comparative reasons, were worth analyzing along with the artifacts and geology samples I was examining. The results of analyses are summarized here.

I picked up numerous samples of the cosmetic known across South Asia "surma" (and nearly everywhere else as "kohl") in the bazaars of Pakistan and India. In many places it is available in both finished and raw form. For example, in the Ajmer bazaar one shop sold boxes of Gulab Sada brand surma right next to a tagari filled with raw chunks of galena (Appendix 12.7 Figure 1 A). In the Harappa town bazaar I purchased a vial of the popular Hashmi brand surma (Appendix 12.7 Figure 1 B), which, along with samples of the cosmetic from several other places, was analyzed when I returned to Madison. The XRD spectrum of the Hashmi surma (and most of the others too) indicated that it contained the lead mineral galena (Appendix 12.7 Figure 1 C). This finding is consistent with other studies on present-day samples of the cosmetic by al-Hazzaa and Krahn 1995, Hardy et al. 1998, Parry and Eaton 1991, and Vaishnav 2001.

I conducted Pb isotope analysis on seven samples taken from modern lead items in Pakistan. These data are listed in Appendix 12.7 Figure 2. Three of the samples were pieces of galena purchased in traditional medicine shops, or *pansaris*. I obtained galena from such shops in Karachi, New Attock City (this sample can be seen in Chapter 3 Figure 2 C) and Harappa Town. At the cave shrine of Lahoot La Makan in the Las Bela District, southern Balochistan, I purchased a small bottle of homemade surma from a herbalist who had a small stand there. The remaining three samples were taken from modern era lead musket balls found on the surface at Harappa.

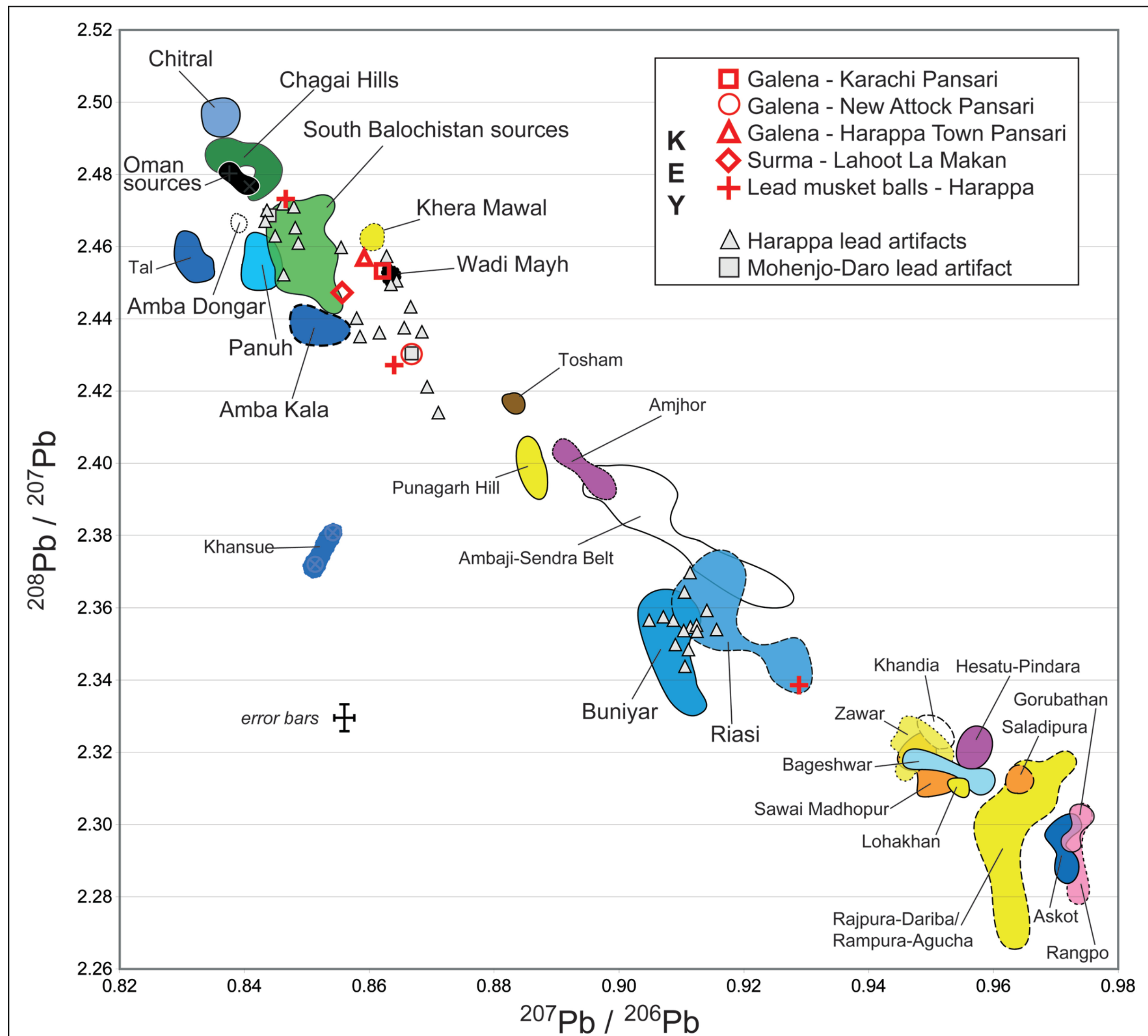
In Appendix 12.7 Figure 3, the Pb isotope data for the seven modern lead samples are plotted in relation to South Asian lead ore fields. For comparative purposes, datapoints for lead analyzed from Harappa and Mohenjo-Daro are plotted on the figure as well. The three pansari-purchased galenas and the surma from the herbalist fall in and around what I have called the "ambiguous" area. Although many Harappan lead artifacts plot in that area, it is poorly characterized with regard to lead sources. The galenas from the Karachi and Harappa Town pansaris do fall adjacent to datapoints for two minor lead occurrences in Oman and southern Rajasthan. However, to my knowledge neither of those deposits are being worked today. The surma sample obtained from the herbalist at Lahoot La Makan plots near the lead sources of southern Balochistan, which would seem to indicate that it was made from regionally acquired galena. While the galena sample from the New Attock City pansari does not resemble any lead deposit in the database, it does share almost identical Pb isotope values with the surma sample analyzed from Mohenjo-Daro. The proprietor of the New Attock City pansari where I bought the samples did not know from where the sample he sold me originated. Still, the fact a modern piece of galena meant to be powdered for surma is isotopically analogous to ancient surma from Mohenjo-Daro is a very important finding, as are the associations of the other modern samples. Together they serve to further demonstrate that the "ambiguous" area is represented by multiple lead deposits in locations,




**Appendix 12.7 Figure 1** **[A]** Surma and galena for sale in the Ajmer bazaar, Rajasthan. **[B]** Hashmi brand surma purchased in the Harappa Town bazaar. **[C]** The XRD spectrum for the Hashmi surma purchased in Harappa Town.

very likely in northwestern South Asia, that remain to be located and isotopically characterized. Unlike the Wadi Mayh lead showing in Oman and the Khera Mawal deposit in southern Rajasthan, which as I have pointed out above are both minor in nature, the sources represented by the "ambiguous" are probably significant as they were exploited during the Harappan Phase and continue to be today. This is assuming, of course, they are even the same deposits at all. It is certainly possible that the modern galenas are from altogether different sources that just happen to have identical isotopic characteristics as the old ones used by the Harappans. For the time being, however, I will assume that the modern and ancient sources are

| **Appendix 12.7 Figure 2** Pb isotope data for modern lead artifacts from Pakistan | | **208/207** | **207/206** | **207/204** |
|---|---|---|---|---|
| New Attock Pansari | galena | 2.4329 | 0.8659 | 15.594 |
| Harappa Town Pansari | galena | 2.4547 | 0.8613 | 15.618 |
| Karachi Pansari | galena | 2.4597 | 0.8588 | 15.633 |
| Lahoot La Makan herbalist | surma | 2.4489 | 0.8563 | 15.634 |
| Harappa Mound ET (H93-3803-24) | lead shot | 2.3377 | 0.9294 | 15.607 |
| Harappa Mound F (H2000-9848-4) | lead shot | 2.4258 | 0.8623 | 15.647 |
| Harappa Mound F (H99-8764-101) | lead shot | 2.4736 | 0.8456 | 15.616 |




**Appendix 12.7 Figure 3** Pb isotope data for modern lead from Pakistan plotted against South Asian lead ore fields.

one and the same and continue searching for them. The shop owner in Harappa Town was also unable to say from where the galena he sold me originated but I was told at the Karachi pansari that their galena came from Balochistan. This then seems like the most promising region to focus on initially, followed by Afghanistan and the great many uncharacterized lead deposits there.

The three musket balls from Harappa each plot with a different lead source area: southern Balochistan, Jammu and the "ambiguous" area. Any or all of these the balls could, of course, contain metal

from multiple deposits and, thus, their positions on the isotope plot may represent points on different source mixing lines. It is, nevertheless, interesting how these lead objects suggest that the same three main source areas exploited during the Harappan Phase continued to be used in the modern (relatively) era.

# APPENDIX 12.8

# PB ISOTOPE DATA FOR COPPER ORES AND SLAGS FROM DEPOSITS IN INDIA, PAKISTAN, IRAN AND OMAN

(*archaeological ore)

| Region | source | material | reference | analysis # | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|---|---|
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu1 | 2.4878 | 0.8327 | 15.782 |
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu2 | 2.4802 | 0.8407 | 15.828 |
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu3 | 2.4763 | 0.8421 | 15.729 |
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu4 | 2.4697 | 0.8424 | 15.758 |
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu5 | 2.4728 | 0.8447 | 15.797 |
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu6 | 2.4838 | 0.8434 | 15.704 |
| Balochistan | Chagai-Saindak | ore | LARCH | ChCu7 | 2.4911 | 0.8315 | 15.807 |
| Gujarat | Ambaji | ore | LARCH | GN-01 | 2.395 | 0.9111 | 15.89 |
| Gujarat | Ambaji | ore | LARCH | GN-02 | 2.4027 | 0.9106 | 15.396 |
| Gujarat | Ambaji | ore | LARCH | GN-03 | 2.4035 | 0.9079 | 15.862 |
| Gujarat | Ambaji | ore | LARCH | GN-04 | 2.3916 | 0.8995 | 15.771 |
| Gujarat | Ambaji | ore | LARCH | GN-05 | 2.4041 | 0.8795 | 15.706 |
| Gujarat | Ambaji | ore | LARCH | GN-06 | 2.3977 | 0.8976 | 15.685 |
| Gujarat | Ambaji | ore | LARCH | GN-07 | 2.3889 | 0.8991 | 15.693 |
| Gujarat | Ambaji | ore | LARCH | GN-08 | 2.3861 | 0.8972 | 15.647 |
| Gujarat | Ambaji | ore | LARCH | GN-09 | 2.3858 | 0.897 | 15.647 |
| Gujarat | Ambaji | ore | LARCH | GN-10 | 2.3879 | 0.8991 | 15.677 |
| Gujarat | Ambaji | ore | Hegde and Ericson 1985 | no # | 2.3891 | 0.904 | 15.649 |
| Himachal Pradesh | Chargaon | ore | LARCH | HP1 | 2.6692 | 0.6834 | 16.639 |
| Himachal Pradesh | Chargaon | ore | LARCH | HP2 | 2.6706 | 0.6801 | 16.662 |
| Himachal Pradesh | Chargaon | ore | LARCH | HP3 | 2.6701 | 0.6813 | 16.69 |
| Himachal Pradesh | Chargaon | ore | LARCH | HP4 | 2.6756 | 0.6801 | 16.678 |
| Himachal Pradesh | Chargaon | ore | LARCH | HP5 | 2.665 | 0.6812 | 16.702 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 96 | 2.4891 | 0.8348 | 15.639 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 101/1 | 2.4935 | 0.8341 | 15.643 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 137 | 2.4934 | 0.8336 | 15.631 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 145 | 2.4861 | 0.812 | 15.661 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 148 | 2.4933 | 0.8319 | 15.617 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 156A | 2.4898 | 0.8193 | 15.656 |
| Iran | Shahr-i-Sokhta | ore* | Hauptmann et al. 2003 | SS 161 | 2.495 | 0.8329 | 15.624 |
| Iran | Chechel Kureh | ore | Hauptmann et al. 2003 | E 127/4111 | 2.4899 | 0.8394 | 15.657 |
| Iran | Chechel Kureh | ore | Hauptmann et al. 2003 | E 128/4112 | 2.4879 | 0.8389 | 15.659 |

| Region | source | material | reference | analysis # | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|---|---|
| Iran | Qaleh Zari | ore | Hauptmann et al. 2003 | E 128/4286 | 2.4913 | 0.8349 | 15.662 |
| Iran | Qaleh Zari | ore | Hauptmann et al. 2003 | E 130/4661 | 2.4906 | 0.8347 | 15.665 |
| Oman | Aarja | ore | Chen and Pallister 1981 | Aarja | 2.4484 | 0.8601 | 15.459 |
| Oman | Al Ajal | ore | Calvez and Lescuyer 1991 | PS12 | 2.4104 | 0.8797 | 15.668 |
| Oman | Al Ajal | ore | Calvez and Lescuyer 1991 | PS18 | 2.4435 | 0.8699 | 15.501 |
| Oman | Al Ajal | ore | Calvez and Lescuyer 1991 | PS17 | 2.4446 | 0.8615 | 15.515 |
| Oman | Bayda | ore | Chen and Pallister 1981 | Bayada | 2.4433 | 0.8627 | 15.438 |
| Oman | Daris 1 | ore | Calvez and Lescuyer 1991 | PS5 | 2.4507 | 0.8559 | 15.488 |
| Oman | Daris 1 | ore | Calvez and Lescuyer 1991 | PS4 | 2.4532 | 0.8557 | 15.443 |
| Oman | Daris 2 | ore | Calvez and Lescuyer 1991 | PS2 | 2.4676 | 0.8454 | 15.6 |
| Oman | Daris 2 | ore | Calvez and Lescuyer 1991 | PS1 | 2.467 | 0.8459 | 15.547 |
| Oman | Gaddamah (near Lasail) | ore | Calvez and Lescuyer 1991 | CU54 | 2.4593 | 0.8545 | 15.533 |
| Oman | Hayl as Safil | ore | Calvez and Lescuyer 1991 | CJ55 | 2.4647 | 0.8453 | 15.603 |
| Oman | Hayl as Safil | ore | Calvez and Lescuyer 1991 | PS16 | 2.455 | 0.8535 | 15.461 |
| Oman | Lasail | ore | Chen and Pallister 1981 | Lasail | 2.4412 | 0.8564 | 15.427 |
| Oman | Maqa'il | ore | Calvez and Lescuyer 1991 | CU73 | 2.4613 | 0.853 | 15.544 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | PS9 | 2.465 | 0.8466 | 15.62 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | CJ58 | 2.4678 | 0.8444 | 15.602 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | CJ57 | 2.468 | 0.8438 | 15.606 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | PS6 | 2.4682 | 0.8431 | 15.608 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | PS8 | 2.4683 | 0.8437 | 15.608 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | PS7 | 2.4691 | 0.8438 | 15.593 |
| Oman | Rakah | ore | Calvez and Lescuyer 1991 | PS10 | 2.4701 | 0.8454 | 15.607 |
| Oman | Zuha | ore | Calvez and Lescuyer 1991 | CU24 | 2.4439 | 0.8568 | 15.451 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG_13 | 2.4613 | 0.8513 | 15.754 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG2.2 | 2.4481 | 0.856 | 15.701 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG2.2_14 | 2.4345 | 0.8682 | 15.849 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG2.5 | 2.4249 | 0.8674 | 15.567 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG2_10 | 2.4534 | 0.8552 | 15.717 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG2_11 | 2.4304 | 0.8689 | 15.745 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG2_12 | 2.4392 | 0.8662 | 15.723 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG7 | 2.4281 | 0.8728 | 15.538 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG6 | 2.4304 | 0.8688 | 15.679 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG8 | 2.4218 | 0.8654 | 15.824 |
| Rajasthan | Ganeshwar | slag | LARCH | RNSG9 | 2.4246 | 0.8634 | 15.565 |
| Rajasthan | Singhana | slag | LARCH | RNSS4 | 2.3798 | 0.8856 | 15.853 |
| Rajasthan | Singhana | slag | LARCH | RNSS5 | 2.3845 | 0.8863 | 15.608 |
| Rajasthan | Singhana | slag | LARCH | RNSS7 | 2.4338 | 0.8603 | 15.723 |
| Rajasthan | Singhana | slag | LARCH | RNSS8 | 2.4354 | 0.8637 | 15.616 |
| Rajasthan | Piplawas | ore | Hegde and Ericson 1985 | no # | 2.2803 | 0.9844 | 15.444 |

| Region | source | material | reference | analysis # | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|---|---|
| Rajasthan | Kankaria | ore | Hegde and Ericson 1985 | no # | 2.3141 | 0.963 | 15.524 |
| Uttaranchal | Askot | ore | LARCH | UT1 | 2.3351 | 0.9547 | 15.746 |
| Uttaranchal | Askot | ore | LARCH | UT10 | 2.3094 | 0.9755 | 15.659 |
| Uttaranchal | Askot | ore | LARCH | UT2 | 2.3013 | 0.9813 | 15.727 |
| Uttaranchal | Askot | ore | LARCH | UT4 | 2.3034 | 0.9823 | 15.518 |
| Uttaranchal | Askot | ore | LARCH | UT5 | 2.3017 | 0.9841 | 15.708 |
| Uttaranchal | Askot | ore | LARCH | UT6 | 2.3001 | 0.982 | 15.686 |
| Uttaranchal | Askot | ore | LARCH | UT7 | 2.3023 | 0.9799 | 15.639 |
| Waziristan | Shinkai | ore | LARCH | WAZ-1 | 2.4671 | 0.8467 | 15.668 |
| Waziristan | Shinkai | ore | LARCH | WAZ-2 | 2.4674 | 0.8478 | 15.664 |
| Waziristan | Shinkai | ore | LARCH | WAZ-3 | 2.4768 | 0.8462 | 15.644 |
| Waziristan | Shinkai | ore | LARCH | WAZ-4 | 2.4812 | 0.8444 | 15.573 |
| Waziristan | Shinkai | ore | LARCH | WAZ-5 | 2.4799 | 0.8465 | 15.603 |

# APPENDIX 12.9

## PB ISOTOPE DATA FOR SEVEN COPPER ORES FROM HARAPPA

| artifact number | ore type | Context | 208/207 | 207/206 | 207/204 |
|---|---|---|---|---|---|
| H94/4999-529 | chalcocite | misc. surface find period unknown | 2.4454 | 0.8485 | 15.312 |
| H90/3008-13 | chalcocite | Mound E – survey, Period 3 or Later | 2.4678 | 0.8434 | 15.309 |
| H90/2070-12 | chalcocite | Mound E – survey, Period 3 or Later | 2.4593 | 0.8452 | 15.479 |
| H90/3008-14 | chalcocite | Mound E – survey, Period 3 or Later | 2.4373 | 0.8610 | 15.148 |
| H90/3022-98 | malachite | Mound E – Tr. 58 Period 3 or later | 2.4652 | 0.8470 | 15.531 |
| H95/4943-8 | malachite | Mound ET – Tr. 28 Period 3 or later | 2.4642 | 0.8473 | 15.203 |
| H90/3126-1 | malachite | Mound E – Tr. 56 Period 3C | 2.4639 | 0.8450 | 15.419 |

# APPENDIX 13.1

## POSSIBLE ROUTES FROM THE INDUS BASIN TO THE SITE OF SHORTUGHAÏ

There are numerous possible routes that Indus Civilization peoples may have taken when traveling to the site of Shortughaï in northern Afghanistan. The major ones emanating from the upper Indus Basin were depicted on Figure 13.9 in Chapter 13. Before reviewing the routes that I believe are suggested by rock and mineral acquisition patterns at Harappa, it is important to at least briefly acknowledge some alternate possibilities. First of all, when journeying to the Shortughaï it is not impossible that Harappans circumvented the Hindu Kush Mountains of Afghanistan altogether, traveling instead toward the west-northwest through the Helmand region and then north to southern Central Asia (Turkmenia). From there they could have continued due east to Bactria and, eventually, Shortughaï. Although this is a circuitous way to get to northern Afghanistan, Francfort points out that (1984a: 172) the Helmand route "is the most probable one between the Harappan world and Turkmenia," where Indus materials have been found at sites like Altyn Depe (Masson 1981). For this reason it should not be ruled out. It is also possible that Harappans utilized a northerly route to Shortughaï but bypassed the highland regions directly west and north of the upper Indus Basin. They could have began such a journey in the lower Indus Basin, traveled via the Bolan and Khojak passes of Balochistan into southeastern Afghanistan and from there moved northward to their destination through the Tarnak Valley and over the Sher-i-Dana and Saling passes. The shortest and most direct routes to Shortughaï from Harappan territory, however, would have originated in the upper Indus Basin. Below I discuss several possibilities.

Harappans from the upper Indus Basin might have embarked on their journey to Shortughaï by first traveling due west, through the Sanghar Pass in the central Sulaiman Range and into northern Balochistan. Travel in this direction would likely have taken them past the large Indus Civilization site of Dabar Kot in the Loralai Valley and, eventually, into the southern Zhob Valley. From there they could have continued west to the Khojak Pass and picked up the second alternate route described in the preceding paragraph or turned north toward the Gomal route, which will be discussed next. Much of the grindingstone, alabaster and some of the vesuvianite-grossular utilized at Harappa (and maybe even white Parh limestone from Loralai too) could have been acquired directly along this northern Balochistan route.

The Gomal Plain may have been an important embarkation area for Harappans traveling to northern Afghanistan. A number of Indus Civilization settlements are now known to have existed in that region including Ghandi Umar Khan, which is located near the Gomal River itself. Harappans could have followed that river to its headwaters, crossed into eastern Afghanistan via the Gomal Pass and then traveled north to their destination from there. Along the way they would have passed not far from the highland Harappan site of Periano Ghundai. Some of the grindingstone and alabaster acquired by residents of Harappa came from sources near the beginning of this route, which Markham noted (1879: 53) was one of the more historically important links between Central Asia and India.

Two main routes lead from the Bannu Basin into eastern Afghanistan – one follows the Tochi River and the other the Kurram River (Thomas and Knox 1994: 93). From their termini near the modern cities of Ghazni and Kabul (respectively) the traveler could

continue on to regions in the north. Although the Kurram route, in particular, was a major thoroughfare for traders and invaders alike during the historic period (Markham 1879: 47-50), it is unclear if it might have also been for Indus Civilization peoples. Some of the raw steatite acquired by residents of Harappa and Mohenjo-Daro may well have come from a source in the Safed Koh Range, which forms part of the northern boundary of the Kurram River Valley. However, no trace of a Harappan presence within the Bannu Basin has been detected in over two decades of archaeological exploration there (Khan et al. 2002: 89).

No Indus Civilization sites (save for Shortughaï) have been discovered north of the Salt Range either. However, there is good reason to suppose that an important route for Harappans journeying to and from northern Afghanistan may have traversed those mountains and proceeded across the Potwar Plateau and through the Peshawar Valley. It has been shown that, during Period 3 at Harappa, site residents acquired alabaster (along with Mari "Diamonds") from the Salt Range, large amounts of steatite from sources not far to the north of the Potwar Plateau, and steatite, vesuvianite-grossular and, perhaps, some chert from occurrences on the margins of the Peshawar Valley. It is highly likely (but not yet confirmed) that they acquired gold, amazonite, mica, nephrite, serpentine and many other varieties of stone and metal from those regions as well. Although Harappans might have obtained these raw materials through one of the other interaction scenarios discussed on pp. 487-489, it is probable that, at least at times, they traveled to or near the actual sources themselves. I have argued (pp. 235 & 239) that in order to identify deposits of white-firing steatite it would have been necessary conduct high-temperature experimental firings and that this would have required technological expertise that Northern Neolithic peoples may not have possessed. If Harappans were the ones who conducted such firings then it is likely that, rather than transport samples hundreds of kilometers to the south, they would have tested them at or near potential sources in the north.

From the Peshawar Valley, Harappans had several options for their onward journey to Shortughaï. They could have traveled west into Afghanistan via the Khyber Pass (passing just 10 km north of the Landi Kotal steatite deposit) and then, upon reaching the Kabul Valley, headed north over the Saling Pass into northern Afghanistan. Or they might have turned eastward before Saling and traveled up the Panjshir Valley and over the Anjuman Pass to the lapis lazuli mines of Badakhshan. From there they would have needed only to have followed the Kokcha River 200 km downstream to its confluence with the Oxus River. Shortughaï is located less than 20 km from that point. Harappans could have also left the Peshawar Valley by a northerly route, passed through the Swat and Chitral valleys (over the Malakand and Lowari passes respectively) and the took the Dorah pass eastward toward Badakhshan and the lapis lazuli mines. A variation on this route would have them exiting the Peshawar Valley from the east, following the Indus River north for a ways and entering the Swat Valley via the Shangla Pass. By doing so, they would have passed nearby the Sherwan steatite deposits in the Hazara region, which is where the large majority of steatite used at Harappa is now known to have been derived.

Indus Civilization peoples may have journeyed to Shortughaï by any or all of the routes described above. However, I would argue that the evidence presented here most favors those routes that first passed through either the Potwar Plateau / Peshawar Valley regions or the Gomal Plain.

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